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Subminiature tubes-prediction of failure and life testing under normal and overload conditions

McNeal, Horace Phillips

Baltimore, Maryland; Johns Hopkins University

SUBMINIATURE TUBES - PREDICTION OF FAILURE AND LIFE TESTING UNDER NORMAL AND OVERLOAD CONDITIONS

by

HORACE PHILLIPS McNEAL

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The author also wishes to express his appreciation to Messrs. R. T. Ellis, Robert Ross, T. W. Sheppard, and L. I. Barbier of The Applied Physics Laboratory, for their cooperation in obtaining equipment, and their interest in the work, without which the experiments would have been impossible.

SUBMINIATURE TUBES - PREDICTION OF FAILURE AND LIFE TESTING UNDER NORMAL AND OVERLOAD CONDITIONS

Chapter I

Introduction

The purpose of this investigation is threefold. First, to make static tests on subminiature tubes, collecting as much data as possible on their behavior at different values of heater voltage and at different values of plate voltage; and to compare uniformity of the same type tube made by two different manufacturers. Second, to make dynamic tests on the same tubes in a circuit which simulates their use in an actual amplifier. The purpose of these tests is to determine tube life, or changes in tube characteristics, under normal load and overload conditions. Third, to attempt to correlate the results of the static tests with the results of the dynamic tests and discover some

method by which static testing may be used to accurately predict which tubes may fail under overload; or to prove that no simple criterion exists for such prediction.

The investigation was sponsored by the Telemetering Group of The Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland, which supplied the subminiature tubes to be tested, approximately 100 each of the following types: a) Manufacturer "S" - Type 6K4-A General Purpose Triode, and b) Manufacturer "R" Type CK608CX Triode.

The general description of the tests to be conducted was contained in a letter to the supervisor of the Telemetering Group from the gentlemen for whom the tests were run. It described the tests as follows: "The first phase will consist of a number of measurements of the parameters of the tubes, with various electrode voltages from normal to less

than normal. The second phase will consist of running the tubes under varying conditions of overload to determine life and types of failure. The final report will attempt to correlate the predicted life with the actual life under overload. It will also show the relative merits of the CK4-A and the CK608".

Chapter II

Description of Static Tests

The static tests consisted of the following:

a) Each tube was tested for internal short circuits.

b) Tubes were operated at rated value of heater voltage (6.3 volts A.C.) and Grid Bias voltage (-2 volts). Plate voltage was set successively at 100%, 80%, 60%, 50%, and 33.3% rated value for Manufacturer "S" Tubes and at 100%, 83.5%, 66.7%, 50%, 33.3% rated value for Manufacturer "R" Tubes. At each value of plate voltage the following quantities were recorded: Grid Bias Voltage, Heater Voltage, Plate current, Heater current, Grid current, Transconductance.

c) Tubes were operated at rated value of Plate Voltage (100volts D.C. for Manufacturer "S" Tubes, 120 volts D.C. for Manufacturer "R" Tubes). Heater voltage was set successively at 100%, 63.5%, 31.8% of rated Heater voltage (6.3

volts A. C.). At each value of heater voltage the following quantities were recorded: Plate Voltage, Grid Bias Voltage, Plate Current, Heater Current, Grid Current, Transconductance.

Description of Tube Testing Equipment Used For Static Tests

The static tests described above were performed in a Navy Type OD-5 Tester. A brief description of this equipment follows as it appears in the Instruction Pamphlet: Model OD-5 Vacuum Tube Analyzing Equipment Supply 110-120 volts 50-60 cycles. Manufacturer: Weston Electrical Instrument Corporation.

"In brief the Model OD equipment consists of the following apparatus: A plurality of vacuum tube sockets designed to accommodate 4 pin, 5 pin, 6 pin, 7 pin, 8 pin minature and acorn tube bases; a transformer supplying 60 cycle power at one of volts at 6.3. At each point of heater voltage the following quantities were recorded: Plate Voltage, Grid Bias Voltage, Plate Current, Heater Current, Grid Current, Transconductance.

Description of Tube Testing Equipment Used for Stable Tests

The stable tests described above were performed in a Navy Type TV-6 Tester. A brief description of this equipment follows as it appears in the instruction book:(1) Model OE Vacuum Tube Analyzing Equipment Supply 110-125 volts 50-60 cycles. Manufacturers: Hickok Electrical Instrument Corporation.

"In brief the Model OE equipment consists of the following assemblies: 1 Assembly of vacuum tube sockets designed to accommodate 4 pin, 5 pin, 6 pin, 7 pin, 8 pin miniature and acorn tube types; a transformer supplying 60 cycle power at one of several standard filament potentials; patch cords for connecting filament power to any pair of socket terminals; a power rectifier supplying filtered direct potential to a system of potentiometers and thence by way of patch cords, to any desired socket terminals; a plurality of electrical indicating instruments suitable for indicating potentials between socket terminals and currents flowing through socket terminals, and a plurality of vacuum tube sockets interconnected with indicating lamps designed to indicate the presence of short circuited tube elements."

"The Model OD equipment measures transconductance by measuring the alternating current produced in the plate circuit by a 60 cycle signal applied to the grid of the tube under test. The grid signal has an effective value of one volt and as transconductance is the ratio of the value of alternating plate current to the value of the alternating grid signal which produced it, it is evident

that the instrument which measured the alternating component of plate current may be calibrated in terms of micromhos of transconductance instead of microamperes of alternating current."

Figure 1 is a block diagram of this tester.

For the purpose of giving qualitative information on the tests, it will be necessary to introduce the identification system used on the tubes. The tubes were assigned a two letter symbol followed by a number. The first letter designates the manufacturer - "S" denoting Manufacturer "S" and "R" denoting Manufacturer "R"; the second letter identifies the lot number - there being three lots of Manufacturer "S" Tubes designated "SA", "SB", and "SC", and four lots of Manufacturer "R" Tubes designated "RA", "RB", "RC", and "RD". Table I in Appendix I identifies the tubes by manufacturers' lot numbers.

In Tables II through VIII of Appendix I

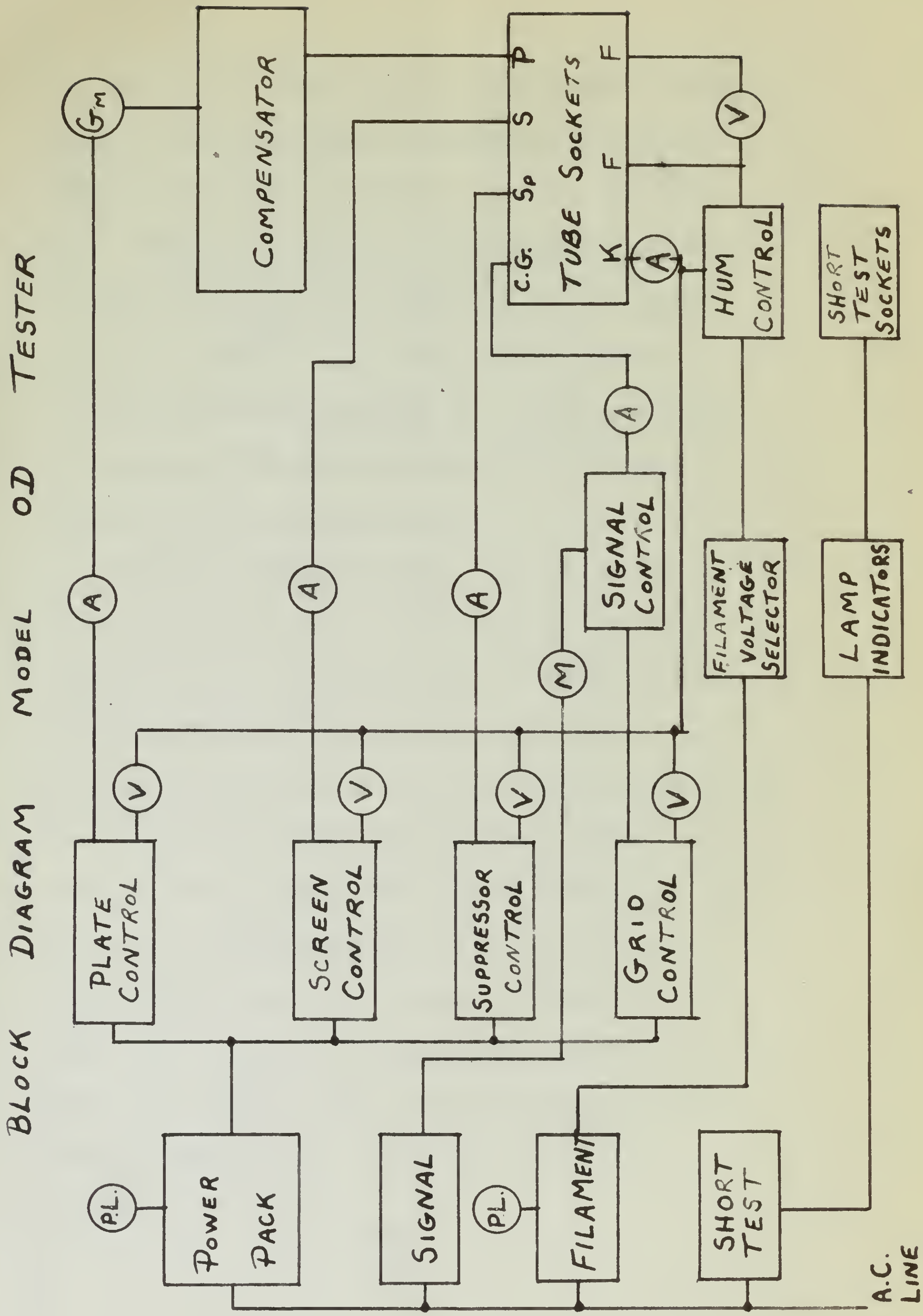

BLOCK DIAGRAM MODEL OD TESTER
Gm
A
V
PLATE CONTROL
SCREEN CONTROL
SUPPRESSOR CONTROL
GRID CONTROL
COMPENSATOR
TUBE SOCKETS
C.G.
Sp
S
P
K
F
F
HUM CONTROL
SHORT TEST SOCKETS
SIGNAL CONTROL
M
FILAMENT VOLTAGE SELECTOR
LAMP INDICATORS
P.L.
POWER PACK
SIGNAL
FILAMENT
SHORT TEST
A.C. LINE

FIGURE 1

are tabulated values of Plate Current, Transconductance, and Plate Resistance for each tube for 100% Plate Voltage and Heater Voltage. Plate resistances were computed by the formula $r_p = \frac{\Delta E\ plate \times 1000}{\Delta I plate}$ where ΔEplate was = 20 volts in each case (i. e. 100 to 80 volts for Manufacturer "S" Tubes and 120 to 100 volts for Manufacturer "R" Tubes). Iplate was in milliamperes.

While a value of ΔEplate of 20 volts may seem too large an increment to take in comput ng plate resistances, it will be seen from the Characteristic Curves (Plates I through VII) that the slope of the curves from 100 to 80 volts in the case of Manufacturer "S" Tubes, and from 120 to 100 volts in the case of Manufacturer "R" Tubes is substantially a constant value. This being the case the twenty volt increment became a reasonable one to take since it eliminated an extra voltage reading on each tube.

The manufacturers give the following as "Typical Operating Conditions" for the Type 6K4-A and CK608CX Tubes:

Manufacturer "S" Type 6K4-A Tubes

Heater Voltage	6.3	6.3	Volts
Heater Current	150	150	Ma
Plate Voltage	100	200	Volts
Grid Bias Voltage	-2	-8	Volts
Plate Current	13.0	11.5	Ma
Amplification Factor	20	16	
Plate Resistance	3640	4650	Ohms
Grid Voltage for Plate current cut-off to 10 amp.	-14	-30	Volts
Transconductance	5500	3450	Micromhos

Manufacturer "R" Type CK608CX Tubes

Heater Voltage	6.3	Volts
Heater Current	200	Ma
Plate Voltage	120	Volts
Grid Bias Voltage	-2	Volts
Plate Current	9.0	Ma *
Transconductance	5000	Micromhos
Amplification Factor	25	

* Manufacturer's Curve Plots this as 8.3 Ma.

A comparison of the average values of I plate and g_m with the Manufacturer's Typical Operating Values is given in the following table (r_p is not included here because Manufacturer "R" Tube Characteristic Sheet quotes no value of r_p).

	Manufacturers Typical I_p milliamps	Actual average I_p milliamps	Diff.
Manufacturer "S" Tubes	13.0	11.2	-1.8
	13.0	15.6	+2.6
	13.0	11.3	-1.7
Manufacturer "R" Tubes	9.0	11.7	+2.7
	9.0	11.0	+2.0
	9.0	9.0	0.0

	Manufac. Typical g_m micromho	Actual average g micromho	Diff.
Manufacturer "S" Tubes	5500	3695	-1805
	5500	4320	-1180
	5500	3675	-1825
Manufacturer "R" Tubes	5000	4150	- 850
	5000	3980	-1010
	5000	3660	-1340

In the next table below the average variations from the mean values of Plate current, plate resistance, and transconductance are given:

	I_{plate}	r_p	g_m	Number good tubes in lot
Manufacturer "S" Tubes	1.77	470	312	34
	1.44	216.2	214.7	33
	1.56	408	292	31
			Total	98
Manufacturer "R" Tubes	.98	316	226.5	9
	1.01	444	215	26
	1.33	892	281	23

	I_{plate}	r_p	g_m	Number good tubes in lot
Manufacturer "R" Tubes	.72	266	195	40
		Total		98

	number bad tubes in lot	% good tubes
Manufacturer "S" Tubes	1	97.1
	2	94.3
	4	88.6
Total	7	
Manufacturer "R" Tubes	1	90
	0	100
	1	96
	0	100
Total	2	

It will be observed that of 105 "S" Tubes tested, 98 were good - percentage 93.4; while for 100 "R" Tubes tested, 98 were good - percentage 98.

Weighted value of average variation from mean value of I_{plate} is computed in Table IX of Appendix I.

Similar computations give the following weighted-in variations from mean value of g_m and r_p.

	Weighted var. of g_m	Weighted var. of r_p	Weighted var. of I_{plate}
Manufacturer "S" Tubes	272.5	320.5	1.591
Manufacturer "R" Tubes	223.0	501.0	.963

The results above lead to the conclusion that Manufacturer "R" CK6080X Tube is more uniform in static characteristics from tube to tube than is the Manufacturer "S" 6K4-A Tube. It is realized that the comparison given in the three tables above is not a measure of the relative merits of the tubes on an absolute basis. It does demonstrate clearly, however, that the manufacturers of the "S" tubes are apt to overrate their tubes more than the manufacturers of the "R" Tubes.

The tubes which were classified as bad

tubes showed the following faults on being tested:

Tubes SA-28, SB-19, SC-8 indicated no internal short circuits, but each drew large excess heater current at rated value of heater voltage.

Tubes SB-33, SC-12, RC-21 drew five percent or less of rated value of plate current at rated value of plate voltage.

Tube SC-15 indicated several internal short circuits, and drew large excess heater current at rated value of heater voltage.

Tube SC-29 drew approximately 50% excess heater current at rated value of heater voltage. The plate current was approximately two percent of rated value at rated value of plate voltage.

Tube RA-7 indicated an internal short circuit from the grid to the heater. It drew a large grid current when the grid bias voltage was applied.

Comparison of Plate Characteristics of Manufacturer "S" and Manufacturer "R" Tubes

From the tests made on the OD Tester, it is possible to plot Plate Characteristic Curves for a grid bias of -2 volts. A plot of the average Plate Characteristic for each tube lot, the Manufacturers Plate Characteristic, and the characteristic of the high and low tube in each lot has been made on Plates I through VII which follow.

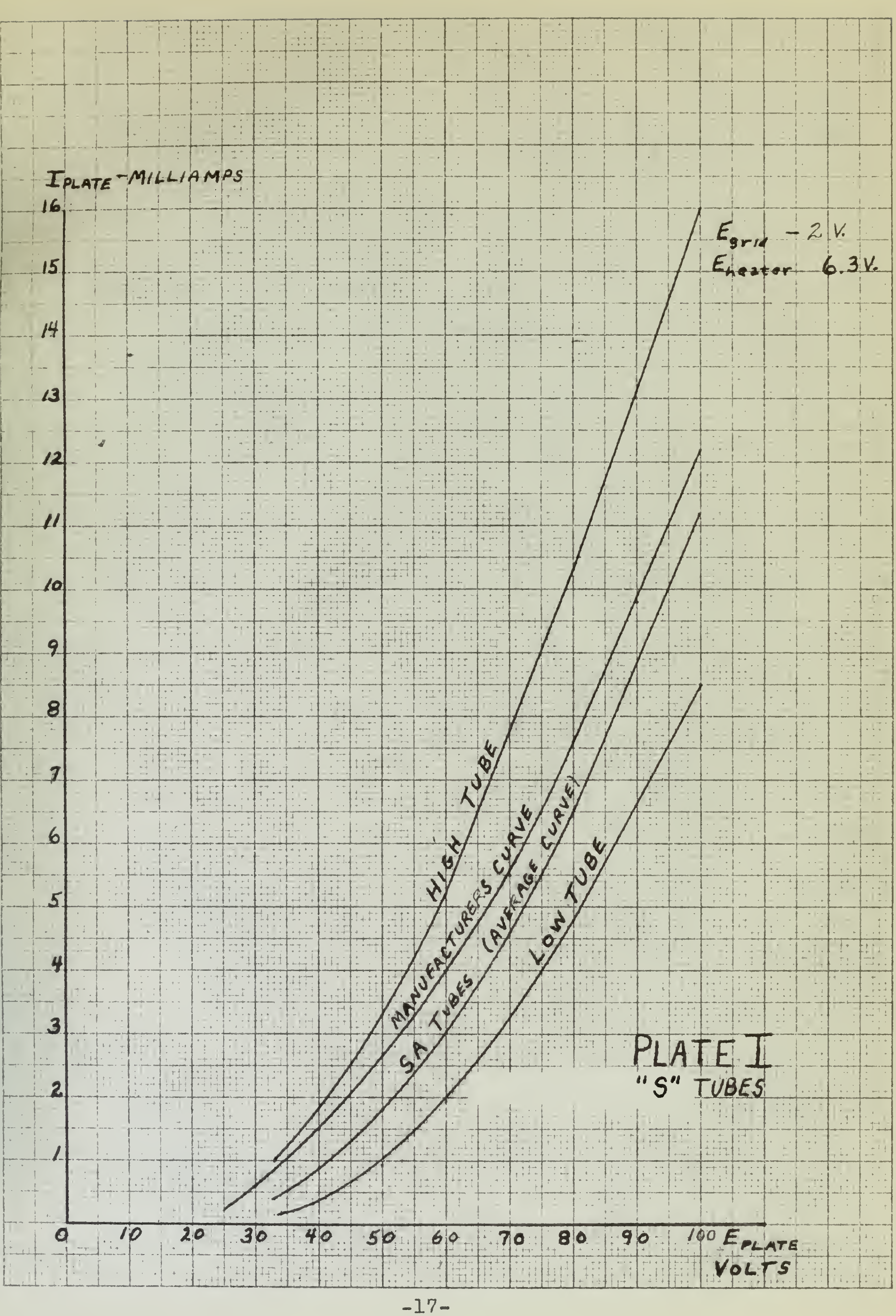
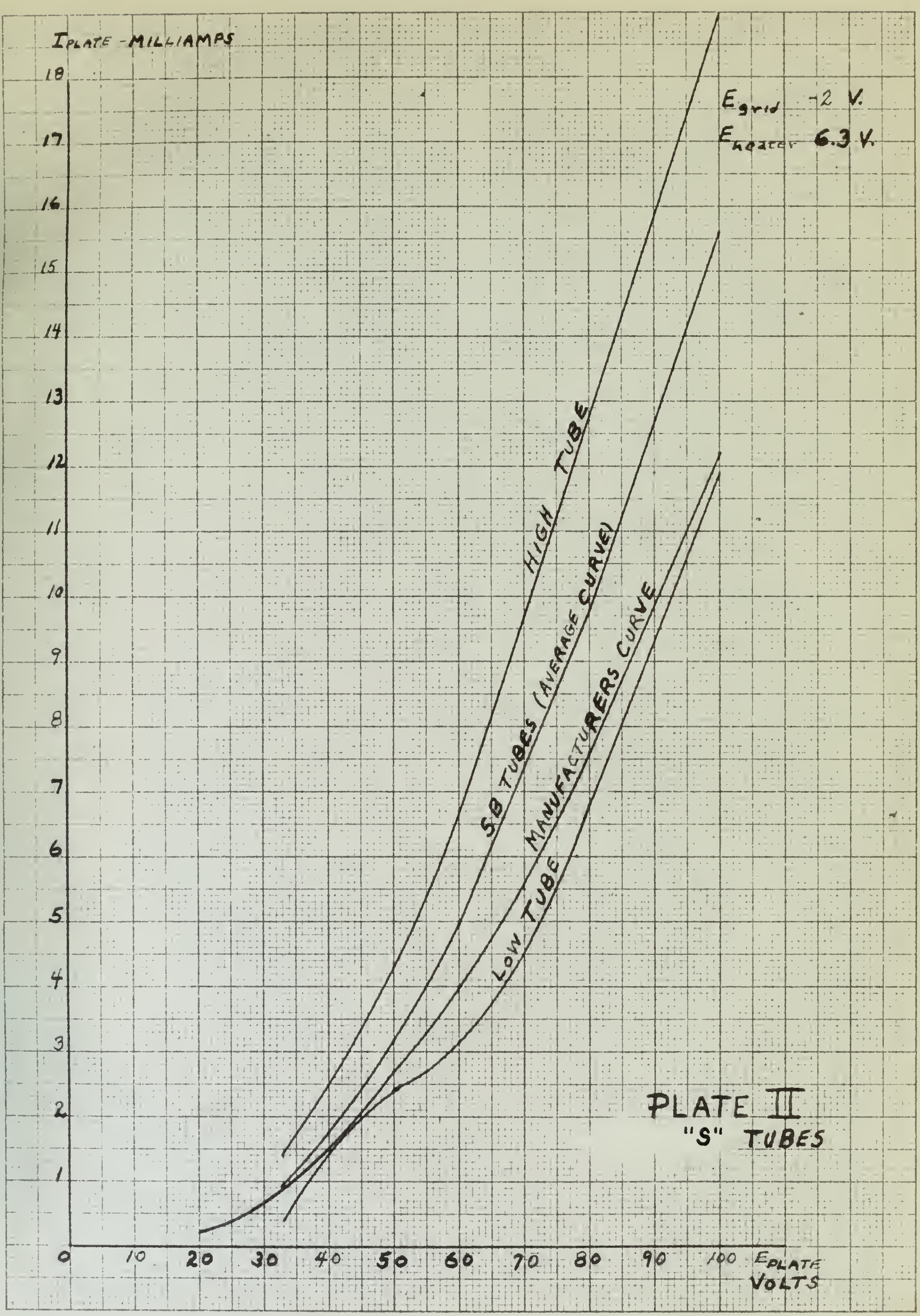
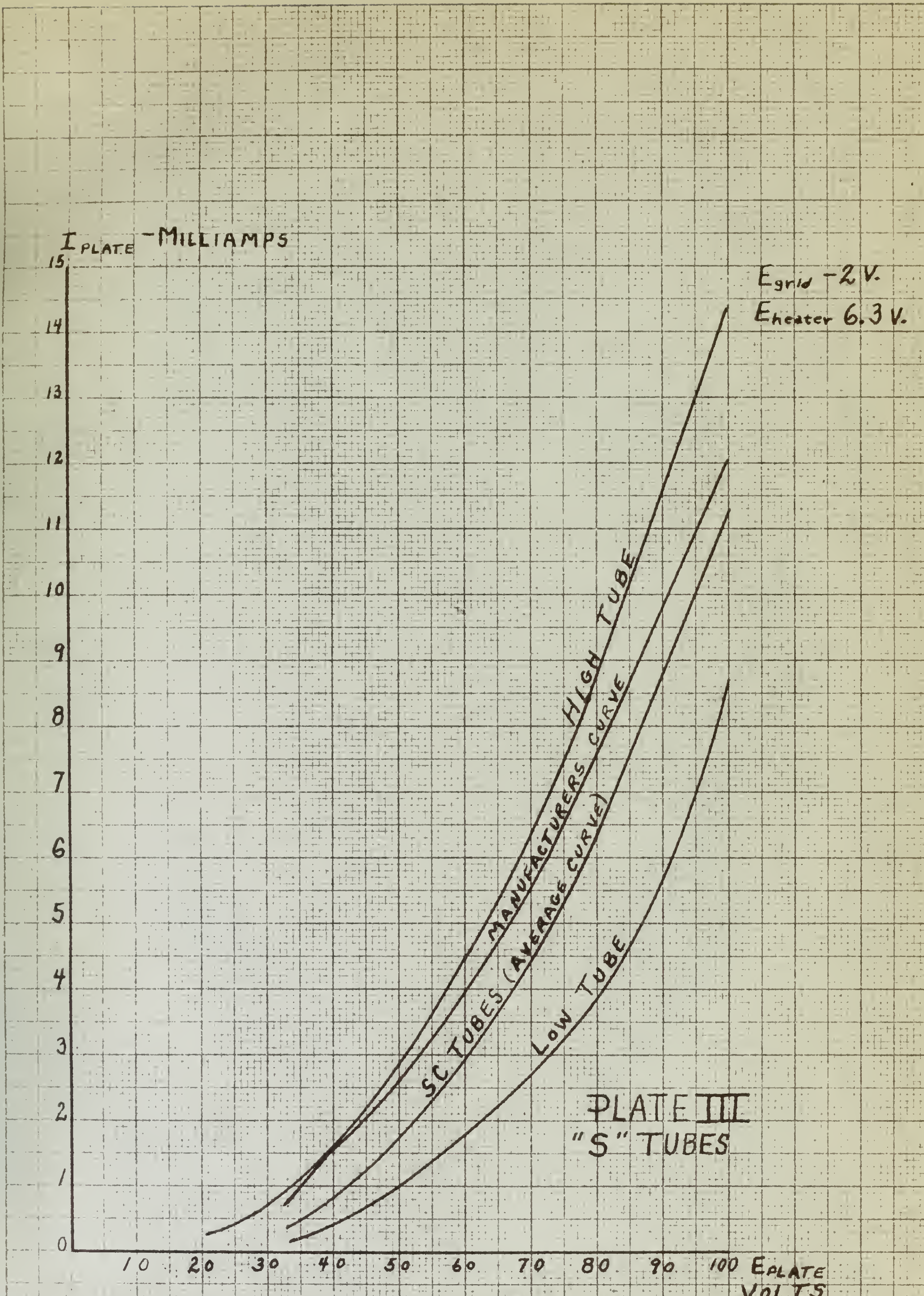


PLATE I
"S" TUBES


IPLATE - MILLIAMPS
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
80
90
100
EPLATE VOLTS
Egrid -2 V.
Eheater 6.3 V.
HIGH TUBE
SB TUBES (AVERAGE CURVE)
MANUFACTURERS CURVE
LOW TUBE
PLATE II
"S" TUBES



I PLATE -MILLIAMPS
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
80
90
100
E PLATE
VOLTS
E grid -2 V.
E heater 6.3 V.
HIGH TUBE
MANUFACTURERS CURVE
SC TUBES (AVERAGE CURVE)
LOW TUBE
PLATE III
"S" TUBES

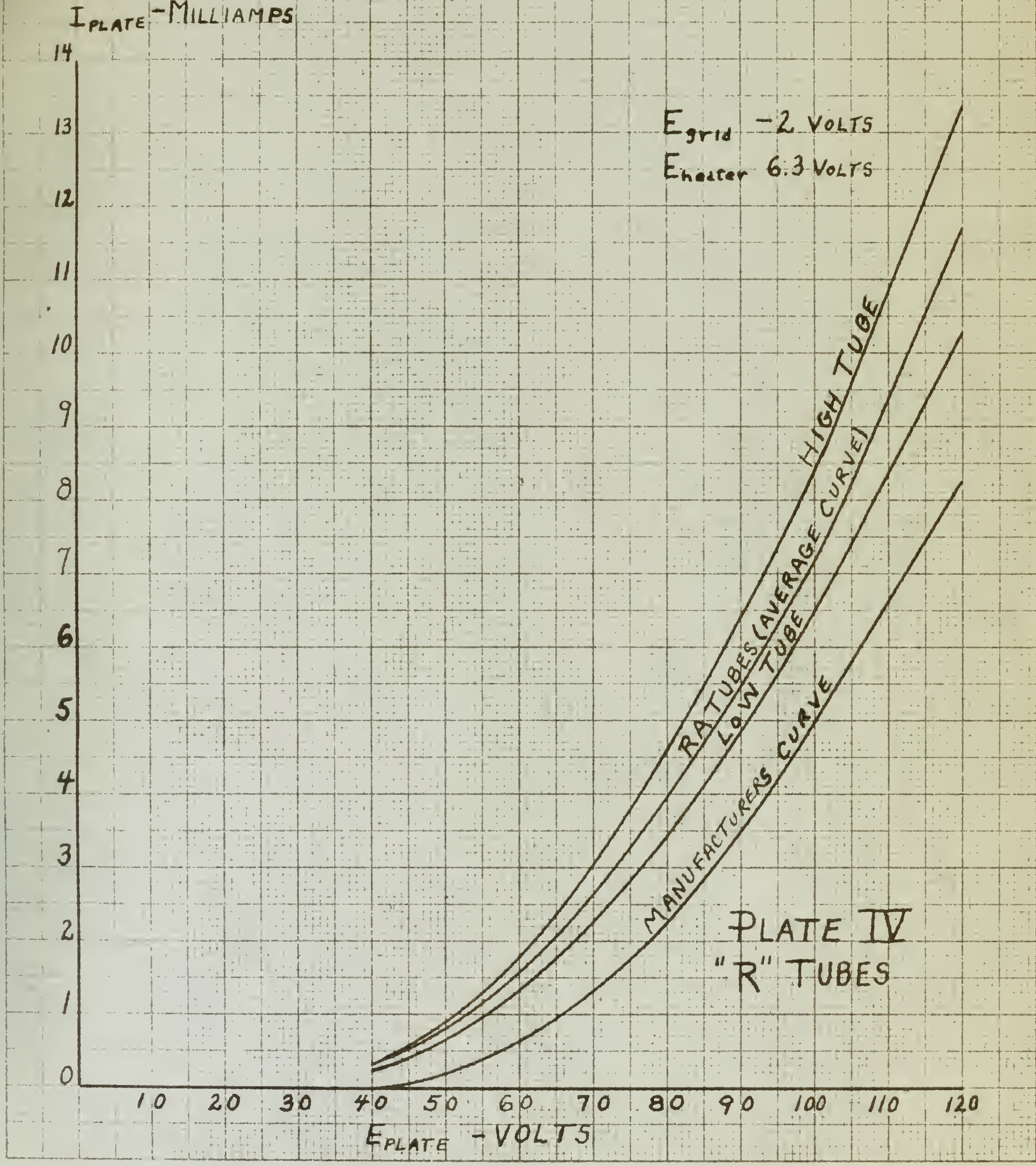


PLATE IV
"R" TUBES

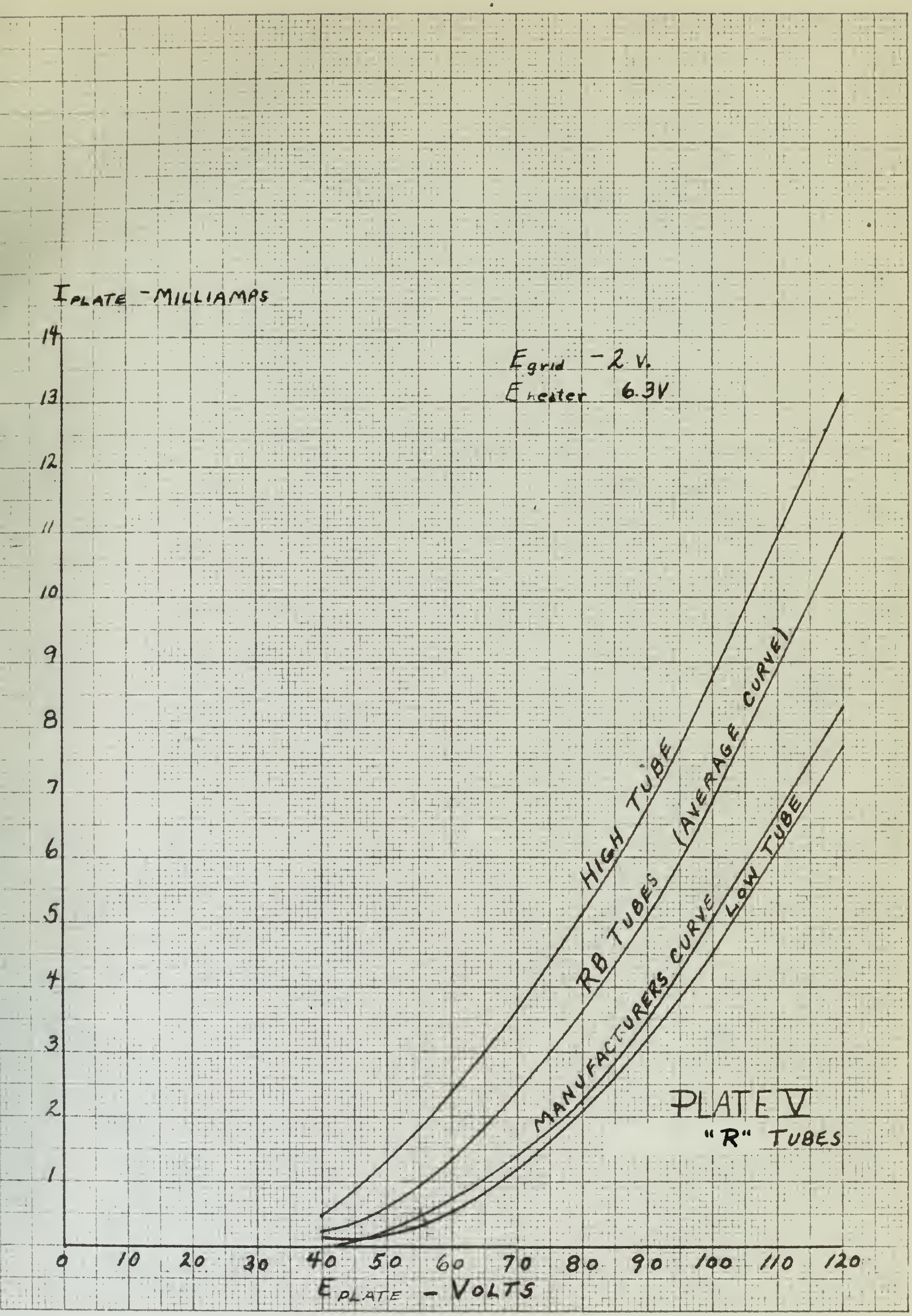
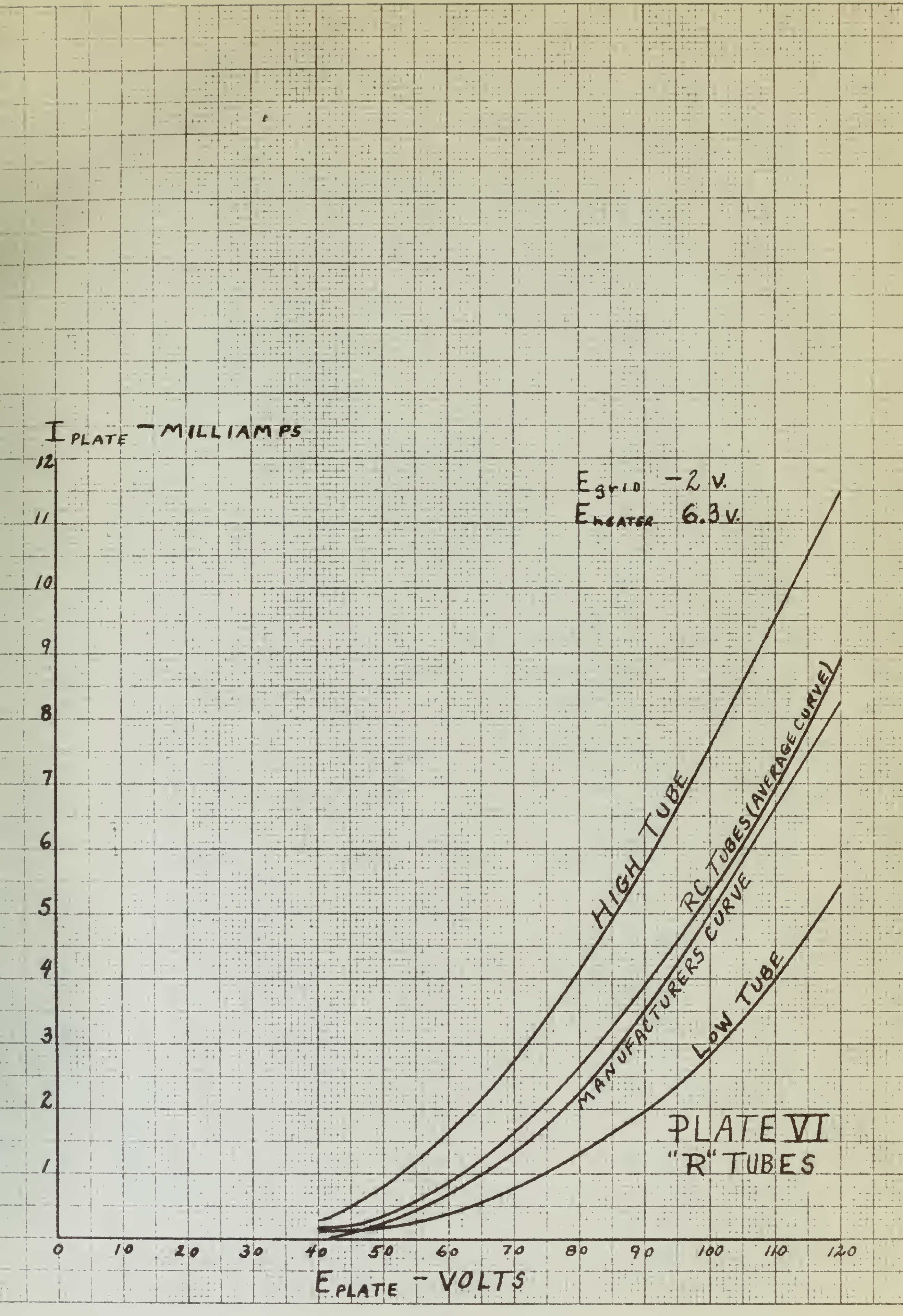
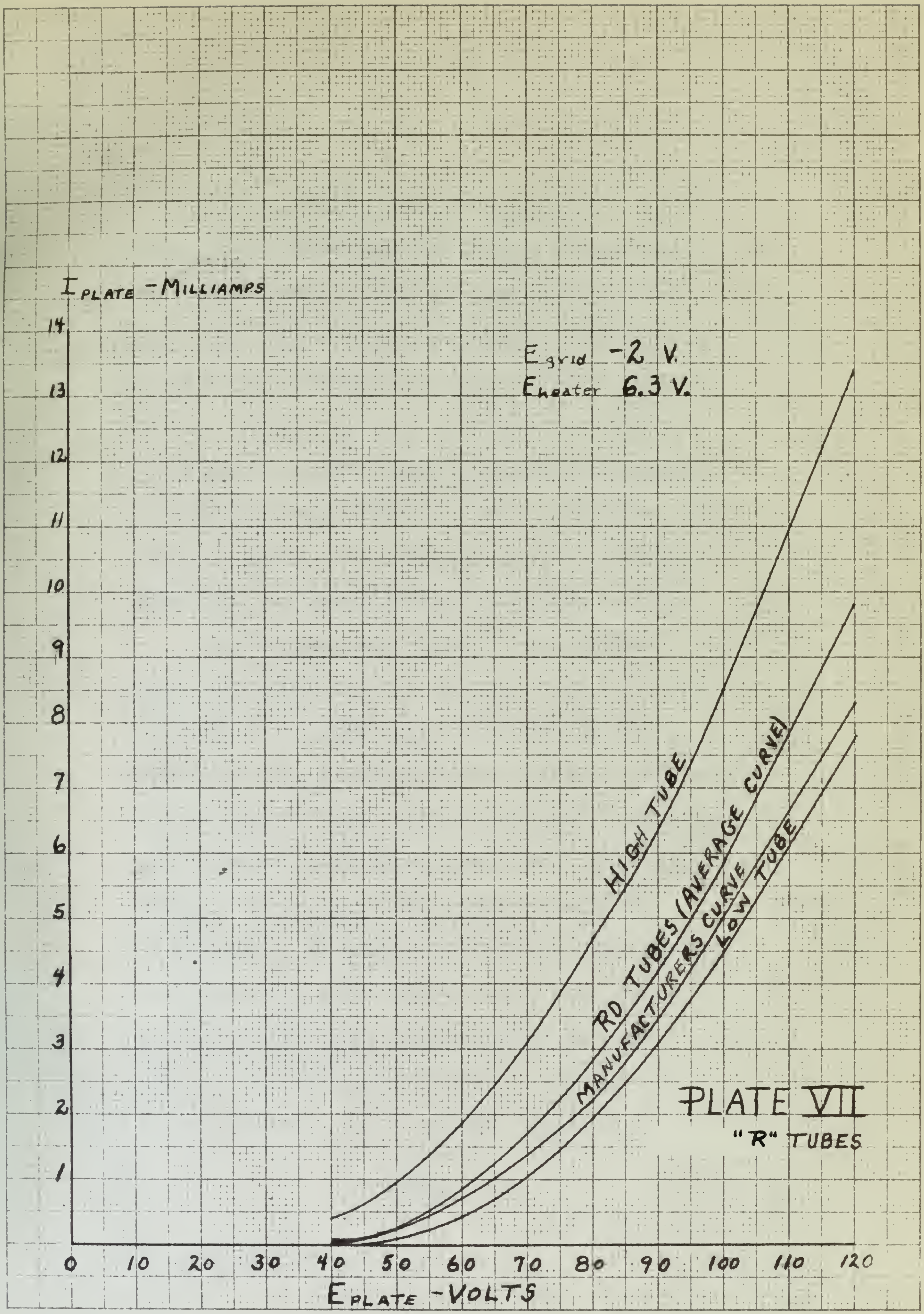


PLATE V

"R" TUBES


I PLATE - MILLIAMPS
12
11
10
9
8
7
6
5
4
3
2
1
0
10
20
30
40
50
60
70
80
90
100
110
120
E PLATE - VOLTS
E GRID -2 V.
E HEATER 6.3 V.
HIGH TUBE
RC TUBES (AVERAGE CURVE)
MANUFACTURERS CURVE
LOW TUBE
PLATE VI
"R" TUBES


I PLATE - MILLIAMPS
14
13
12
11
10
9
8
7
6
5
4
3
2
1
E grid -2 V.
E heater 6.3 V.
HIGH TUBE
RD TUBES (AVERAGE CURVE)
MANUFACTURERS CURVE
LOW TUBE
PLATE VII
"R" TUBES
0
10
20
30
40
50
60
70
80
90
100
110
120
E PLATE - VOLTS

Examination of the curves in Plates I through VII shows two important points about the tubes. First, the average characteristic curve for the Manufacturer "R" Tubes is in each case higher than the Manufacturers Curve. In the case of the Manufacturer "S" Tubes in two cases out of three, it is lower than the manufacturer's curve. Secondly, the spread between high and low tube in a lot is greatest for Manufacturer "S" Tubes Lot SA.

One interesting point in connection with the static tests was the appearance in some tubes of small grid currents of the order of 100 to 700 microamps when heater voltage was set at 6.3 volts and no grid bias nor plate supply voltage was applied. This grid current was present in approximately 40% of the tubes of each manufacture. The tubes in which this grid current appeared tested in general above the average values of plate current and transconductance. For example in one lot this grid current appeared in 10

of 35 tubes. The average I_{plate} for these 10 tubes was 12.9 m.a. compared with an average value of 11.3 m.a. for the entire lot. The average g_m for these same 10 tubes was 4130 micromhos compared to 3675 micromhos for the entire lot.

Tubes in which the grid current appears probably have cathodes of better emission characteristics than those of the tubes in which this current does not appear.

CHAPTER III

DESCRIPTION OF DYNAMIC TESTS

The dynamic tests were made to simulate the performance of an amplifier tube in a very high frequency F-M transmitter. A circuit diagram of the transmitter if given as Figure 2. Specifications for the transmitter are as follows:

R.F. Output Impedance	51.5 ohms	
Tuning Range	209 mc to 227 mc.	
Nominal Power Output	0.5 watt	

Typical Operation:

Plate Supply Voltage	130 V.D.C.	115 V.D.C.
Plate Current	45 ma	35 ma
Heater Current	0.45 amp.	0.45 amp.
Power Output (51.5 ohm)	0.5 watt	0.5 watt

To reproduce exactly the conditions which exist in the amplifier of this transmitter, it would be necessary to build the complete unit according to specifications taking necessary precautions to shield the

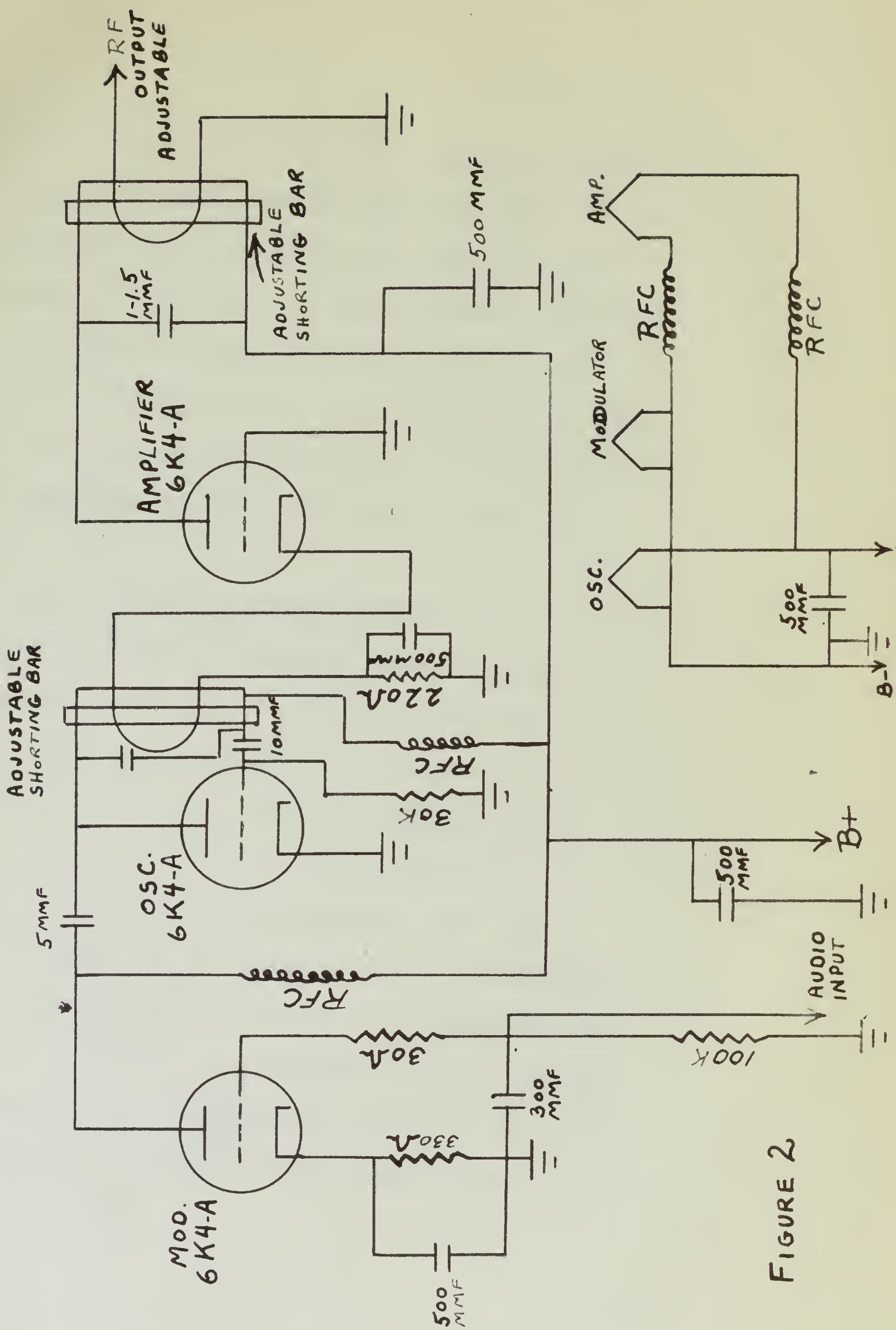

RF OUTPUT ADJUSTABLE
ADJUSTABLE SHORTING BAR
1-1.5 MMF
500 MMF
AMPLIFIER 6K4-A
AMP.
MODULATOR
RFC
RFC
OSC.
500 MMF
A+
B- A-
ADJUSTABLE SHORTING BAR
500 MMF
220Ω
10 MMF
RFC
30K
OSC. 6K4-A
5 MMF
B+
500 MMF
AUDIO INPUT
RFC
30Ω
100K
300 MMF
330Ω
MOD. 6K4-A
500 MMF

FIGURE 2

various stages, use leads to tubes as short as possible, and observe strictly all ordinary precautions to eliminate stray capacitances. This procedure would permit the testing of only one amplifier tube at a time. It would also be necessary to solder the leads of each tube in place for test, as there are no base pins or tube sockets for this type tube.

In view of the above stated conditions, and because it was desired to run normal load and particularly overload tests on as many tubes as possible, a simulator circuit using low frequency input was decided upon. The advantages of such a circuit from the testing point of view are many: a) Use of shielding in the chassis is not necessary. b) Several tubes can be tested simultaneously. c) Tubes can be mounted in tube socket adapters which are easily removable and in which tubes can be quickly inserted without soldering.

The simulator circuit used is believed to be as close an approximation to the actual circuit as can be had using low frequency. The power outputs of the tubes in the simulator circuit can be adjusted to values reasonably close to the output obtained on test of the transmitter, depending on the uniformity of the ten tubes being tested.

Admittedly the simulator circuit is an alternative method of testing because it is generally accepted that the only real test of how a particular tube will perform in a particular circuit is its performance in that circuit. When the time requirements for testing in the actual circuit are considered, however, it is apparent that if more than a "handful" of tubes are to be tested singly an enormous amount of time would be required. The nine twenty hour tests described below would have required 1800 hours running time had the tubes been tested singly.

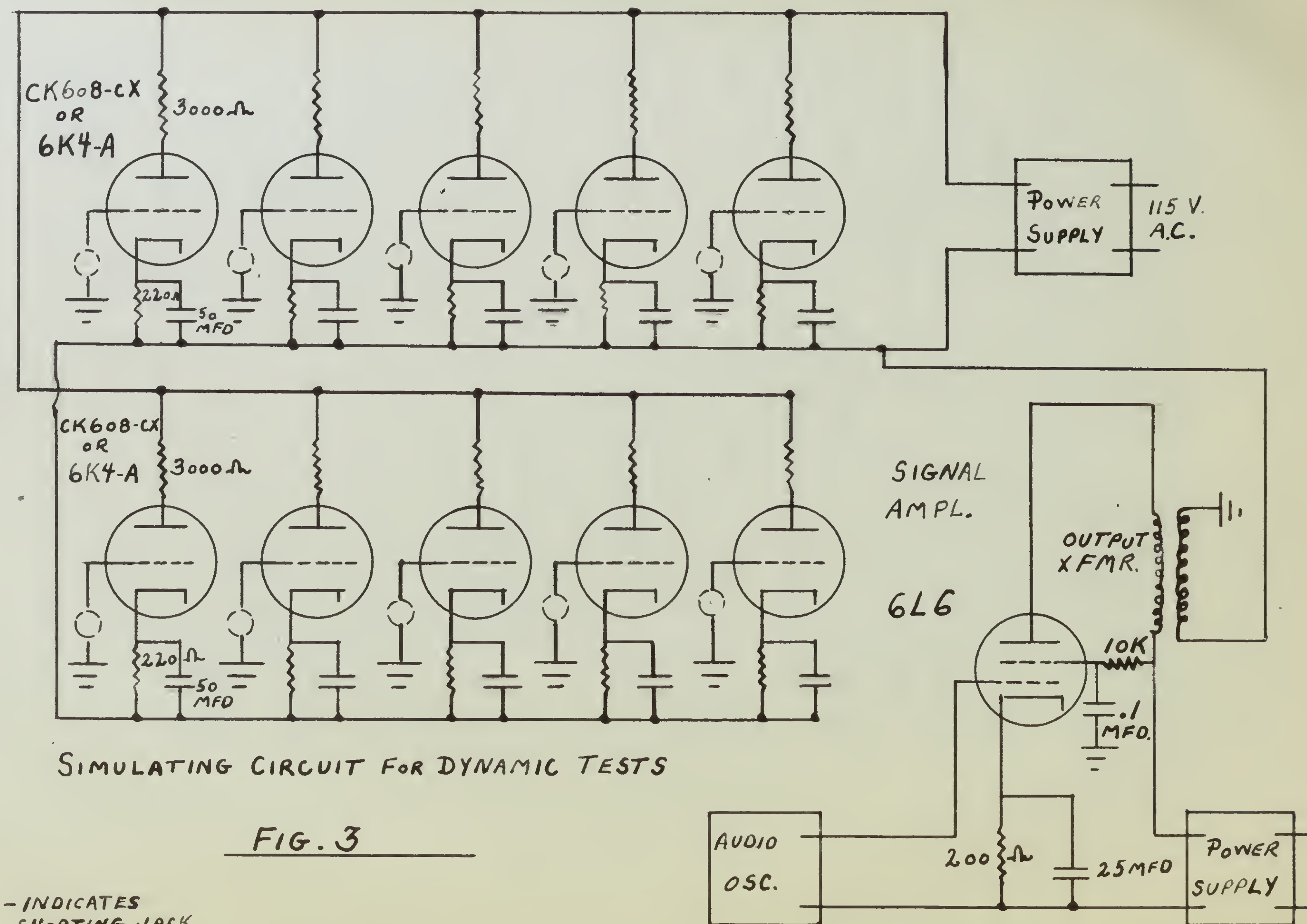
The circuit used to simulate the operation of the amplifier in the VHF Transmitter is shown in Figure 3. Originally a signal input frequency of 60 cycles per second was to be used. The impedance of the test circuit was so low, however, that a capacitor of approximately 100 mfd. would have been required across the power supply output to make the impedance of this capacitor small compared to the test circuit impedance. A signal frequency of 1000 cycles per second was therefore used, which was amplified before being applied to the test circuit.

As will be seen from the circuit diagram, the ten tubes to be tested were connected in parallel as separate amplifier tubes using common plate supply voltage and input signal sources. The cathode resistors were made 220 ohms, the same value used in the original circuit. The by-pass capacitors across the cathode resistors were made 50 mfd. to assure adequate by-passing of alter-

nating current at low frequency. The value of the load resistors was chosen as 3000 ohms to be of the same order of magnitude as the plate resistance of the tubes, which is listed as 3640 ohms for the 6K4-A Tube at 100 volts plate voltage and -2 volts grid bias.

It will be seen from the circuit diagram that the cathodes of the tubes being tested were not grounded, but were connected to the minus side of the plate power supply. The signal voltage at 1000 cycles per second was applied at the same point as the minus side of the power supply. This connection makes the minus side of the power supply above ground potential by the amount of the signal voltage; but in view of the small value of signal voltage used (6.2 volts r.m.s. maximum), this is of no consequence.

The first tests were of twenty hours duration. Twenty hours intermittent operation was



SIMULATING CIRCUIT FOR DYNAMIC TESTS

FIG. 3

( ) - INDICATES SHORTING JACK

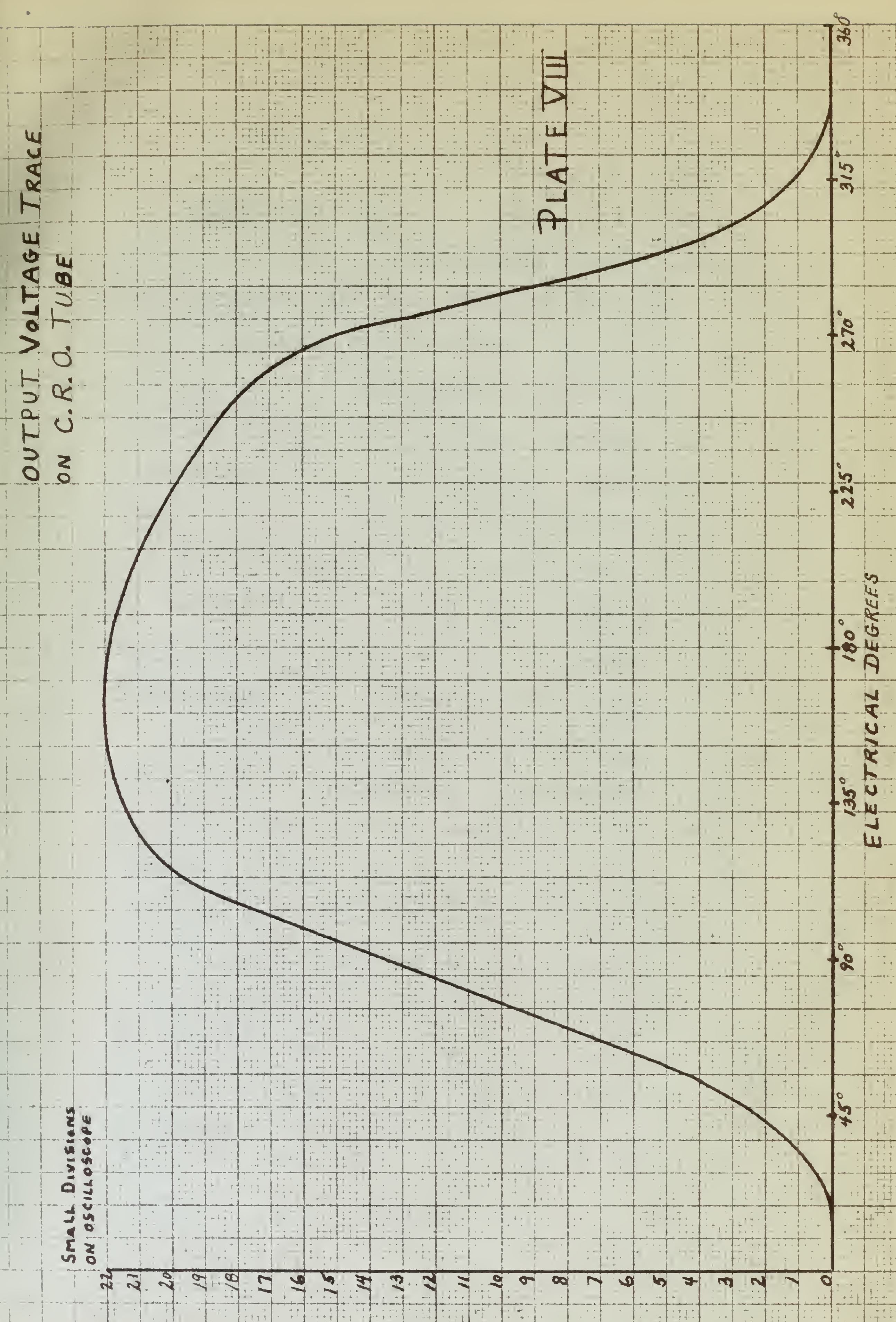
considered, by Applied Physics Laboratory, to be satisfactory life for the transmitter in which the tubes are used.

Measurements were made in the following manner: a) Plate supply voltage was measured by a voltmeter on the power supply which was corrected by comparison with the reading of a Weston 1000 ohms per volt laboratory type meter placed across the output terminals of the power supply. b) Total plate current was measured by a D.C. milliammeter in the output circuit of the plate power supply. c) Grid current was measured by a D.C. milliammeter of 0 - 10 m.a. range which was placed in the grid circuit of each tube successively by means of a phone plug inserted in a shorting jack. This meter was shunted by a 5 mfd. capacitor. d) Output power was measured by means of Cathode Ray Oscillograph. The vertical deflection plates of the oscilloscope were connected directly from the positive side of the plate power supply to considered, by Applied Physics Laboratory, to be satisfactory life for the transmitter in which the tubes are used.

Measurements were made in the following manner: a) Plate supply voltage was measured by a voltmeter on the power supply which was corrected by comparison with the reading of a Weston 1000 ohms per volt laboratory type meter placed across the output terminals of the power supply. b) Total plate current was measured by a D.C. milliammeter in the output circuit of the plate power supply. c) Grid current was measured by a D.C. milliammeter of 0 - 10 m.a. range which was placed in the grid circuit of each tube successively by means of a phone plug inserted in a shorting jack. This meter was shunted by a 5 mfd. capacitor. d) Output power was measured by means of Cathode Ray Oscillograph. The vertical deflection plates of the oscilloscope were connected directly from the positive side of the plate power supply to the plate of the tube whose power was being measured. This connection gave a trace on the oscilloscope of the voltage existing across the load resistor of the tube. This voltage trace was plotted on cross section paper and from the plot the power was calculated. A sample plot is given as Plate VIII and a sample power calculation from this plot is given in Table XI of Appendix I.

Plates VIII - A, and VIII - B are plots of the grid and plate voltage traces of the Manufacturer "S" and Manufacturer "R" Tubes respectively. These plots were made for the same plate supply and signal voltages on each tube. They represent typical operation of the tubes in the simulator.

Plate VIII - C is a plot of grid bias voltage versus plate current for tubes SB-27 and RB-12 at E_{plate} = 127, 100, 60 volts. The dynamic operation lines for each tube are drawn on this plot for conditions of operation shown in Plates VIII A and B.


OUTPUT VOLTAGE TRACE
ON C.R.O. TUBE
PLATE VIII
SMALL DIVISIONS
ON OSCILLOSCOPE
ELECTRICAL DEGREES
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
45°
90°
135°
180°
225°
270°
315°
360°

Plates VIII D and E are predicted plate voltage curves using the dynamic characteristics of Plate VIII C and the grid voltage curves of Plates VIII A and B. The actual curves obtained are plotted on the same sheet. Dashed portions of each curve are the extrapolated portions. The large difference between the curves at low values of plate voltage is caused by the fact that the grid is positive in this region and no data is available from curves of Plate VIII C on plate current for positive grid voltage.

The oscilloscope calibration of 4.9 volts per small scale division (49 volts per inch deflection) was obtained in the following manner: a) A D.C. voltage of known value was placed directly on the vertical deflection plates of the oscilloscope, (Dumont Type 208-B Cathode Ray Oscillograph). The deflection was found to be 10 small divisions (1 inch) per 49 volts D.C. b) An A.C. Voltage from an audio oscillator which

measured 15 volts r.m.s. was placed on the vertical deflection plates after the D.C. signal was removed. The deflection for this signal was 9 small divisions peak to peak, or 4.5 divisions peak value. Peak value of 15 volt r.m.s. signal = 15 x $\sqrt{2}$ = 21.2 volts

$\frac{21.2 \text{ volts}}{4.5 \text{ divisions}} = 4.7$ volts/division

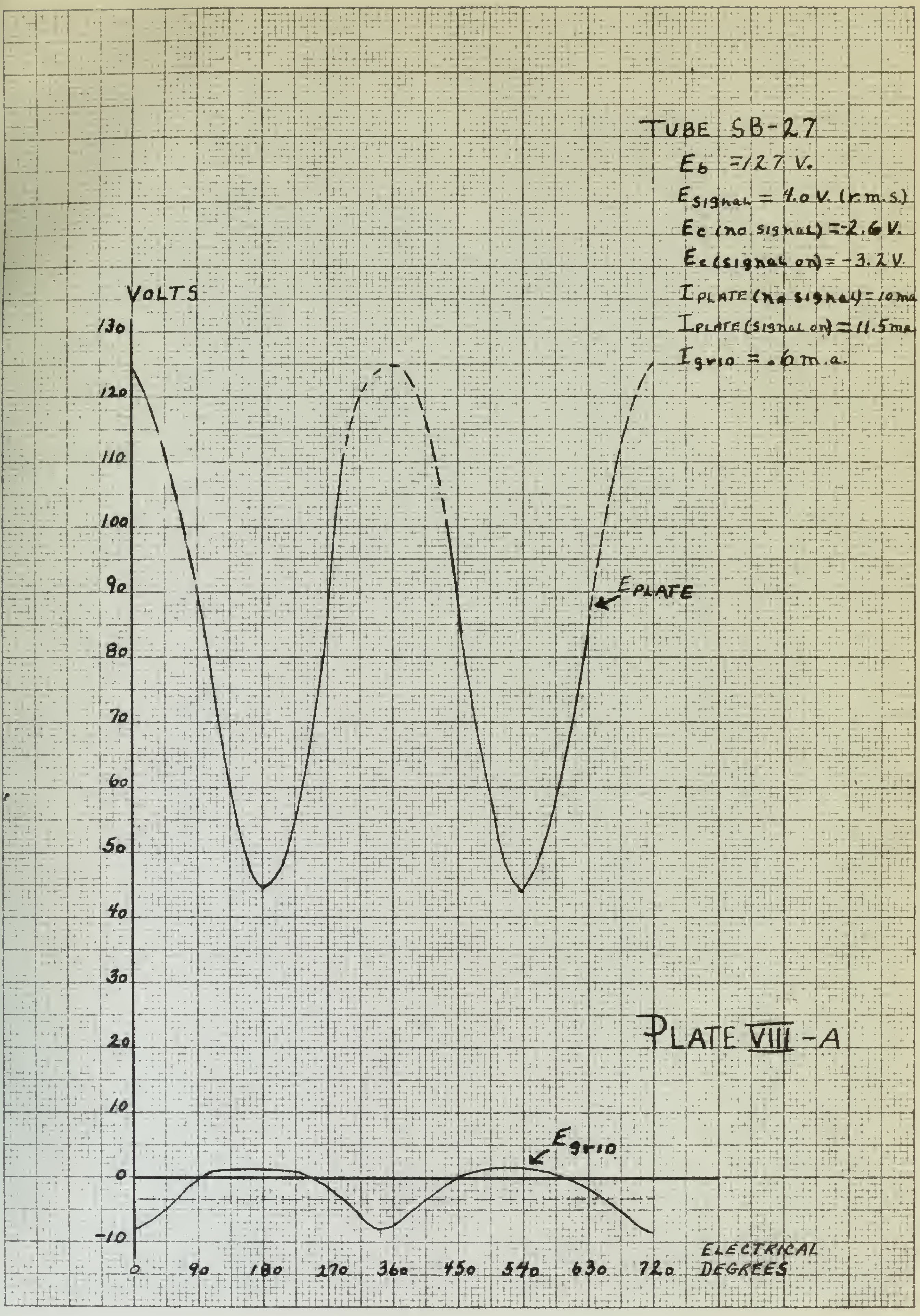
It was decided that 4.9 volts / division was a sufficiently accurate value and this value was used.

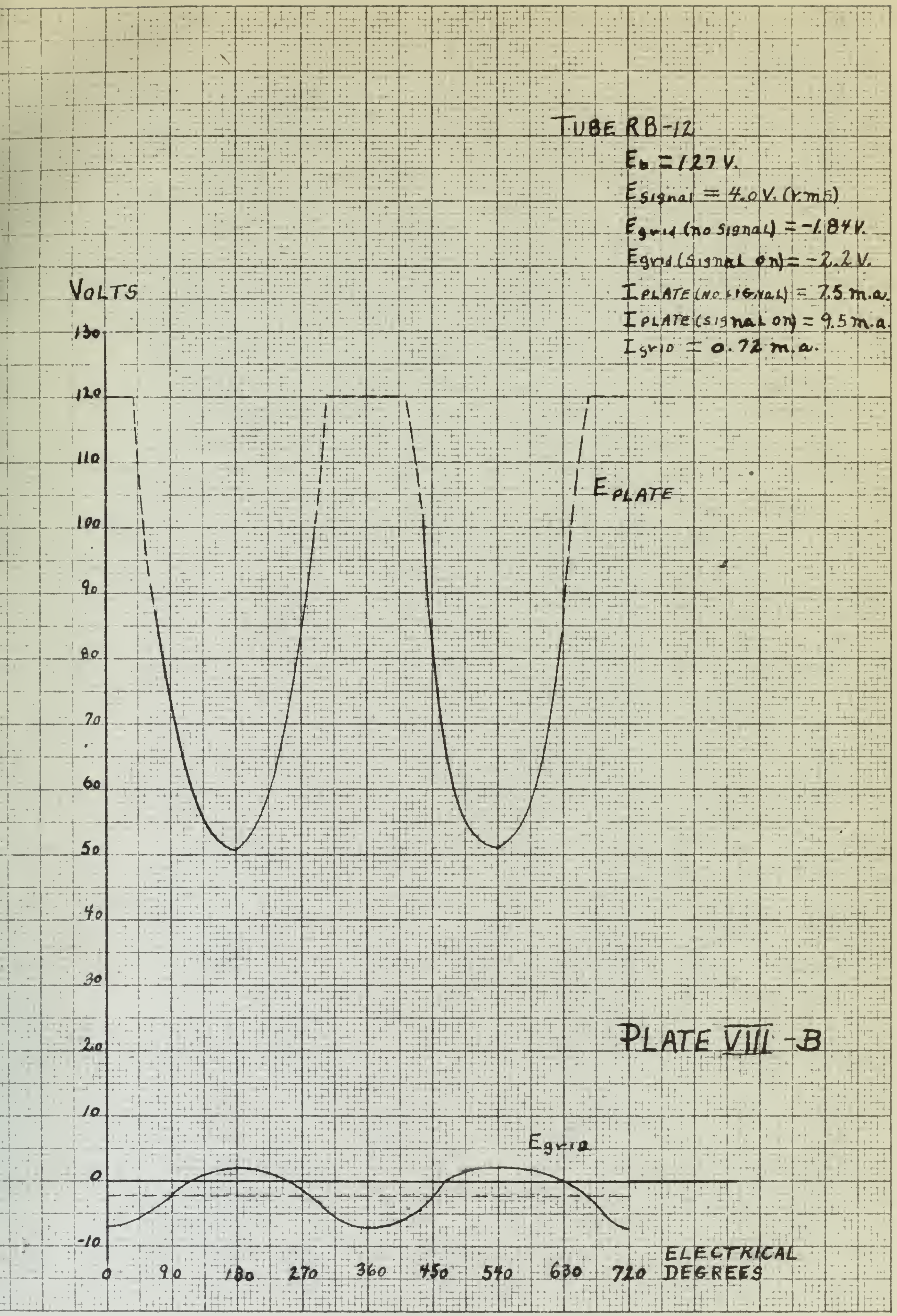
Actual Procedure Used for Tests

The procedure of testing in the simulating circuit shown in Figure 3 was as follows:

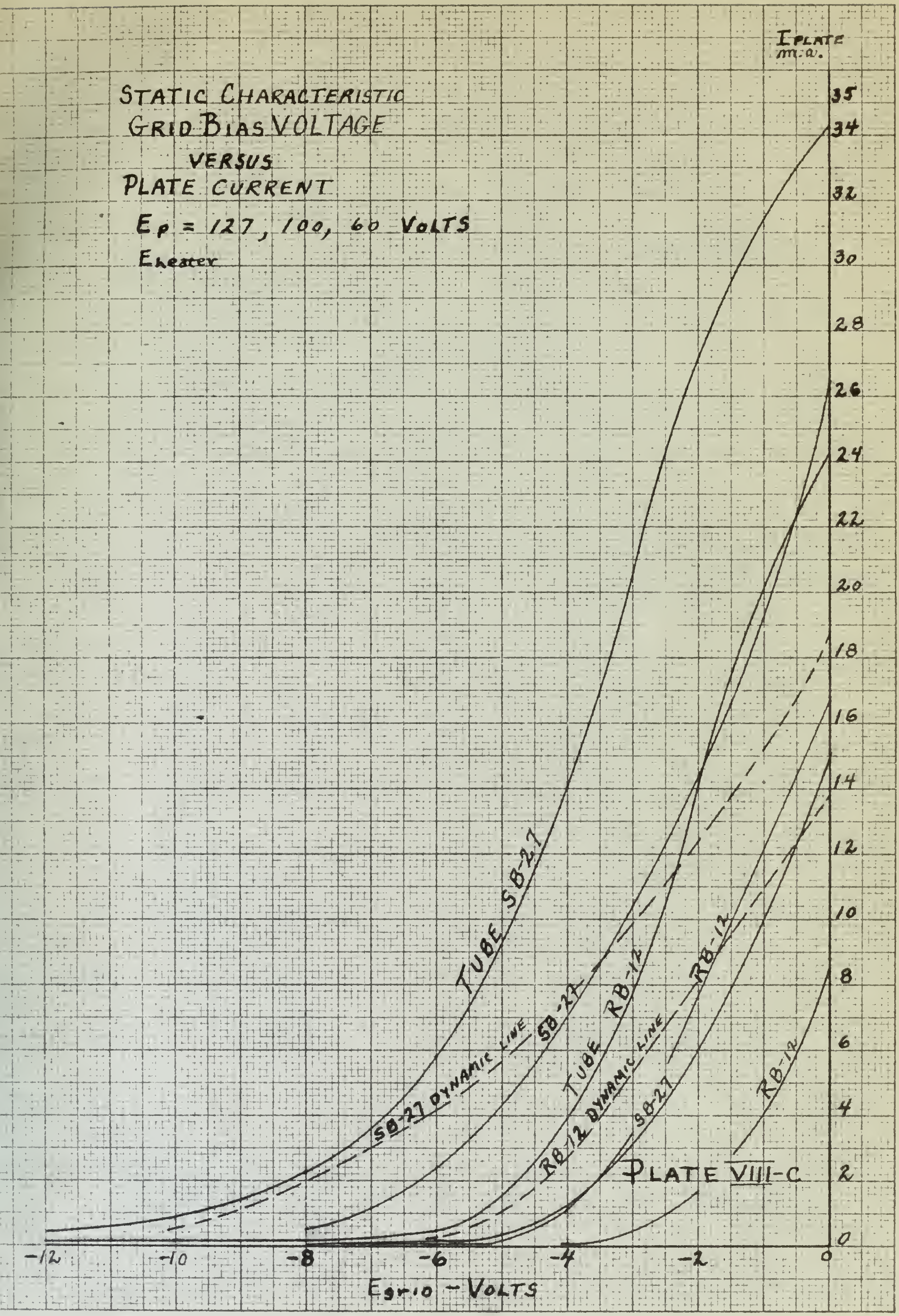
a) Ten tubes were tested simultaneously (unless there were not ten good tubes in one lot).

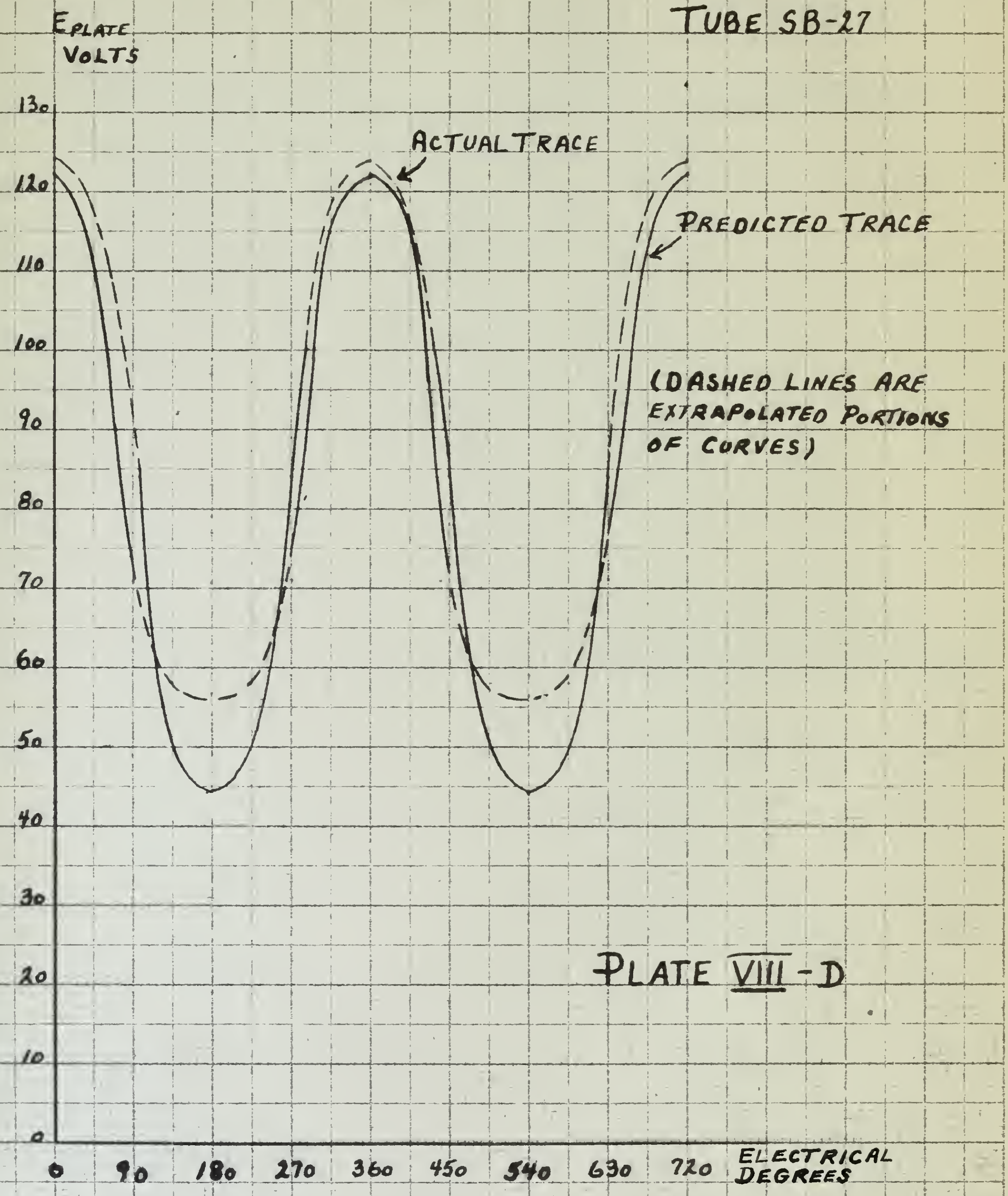
b) Plate supply voltage was adjusted whenever it was observed to have drifted from the desired value for the particular test. The plate voltage used for each test was determined by the "cut and try" method to obtain the power output desired with a reasonable value of signal voltage applied. The power output


TUBE SB-27
Eb =127 V.
E signal = 4.0 V. (r.m.s.)
Ec (no signal) = -2.6 V.
Ec (signal on) = -3.2 V.
I PLATE (no signal) = 10 ma
I PLATE (signal on) = 11.5 ma
I grid = .6 m.a.
VOLTS
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
E PLATE
E grid
PLATE VIII -A
0
90
180
270
360
450
540
630
720
ELECTRICAL DEGREES



TUBE RB-12
E_b = 127 V.
E_signal = 4.0 V. (r.m.s)
E_grid (no signal) = -1.84 V.
E_grid (signal on) = -2.2 V.
I_PLATE (NO SIGNAL) = 7.5 m.a.
I_PLATE (signal on) = 9.5 m.a.
I_GRID = 0.72 m.a.
VOLTS
130
120
110
100
90
80
70
60
50
40
30
20
10
0
-10
E_PLATE
E_grid
0
90
180
270
360
450
540
630
720
ELECTRICAL DEGREES
PLATE VIII-B


STATIC CHARACTERISTIC
GRID BIAS VOLTAGE
VERSUS
PLATE CURRENT
E_p = 127, 100, 60 VOLTS
E_{heater}
I_{PLATE} m.a.
35
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
-12
-10
-8
-6
-4
-2
0
E_{grid} - VOLTS
TUBE SB-27
SB-27 DYNAMIC LINE
SB-27
TUBE RB-12
RB-12 DYNAMIC LINE
RB-12
SB-27
RB-12
PLATE VIII-C



TUBE SB-27
E PLATE VOLTS
130
120
110
100
90
80
70
60
50
40
30
20
10
0
ACTUAL TRACE
PREDICTED TRACE
(DASHED LINES ARE EXTRAPOLATED PORTIONS OF CURVES)
0
90
180
270
360
450
540
630
720
ELECTRICAL DEGREES

PLATE VIII - D

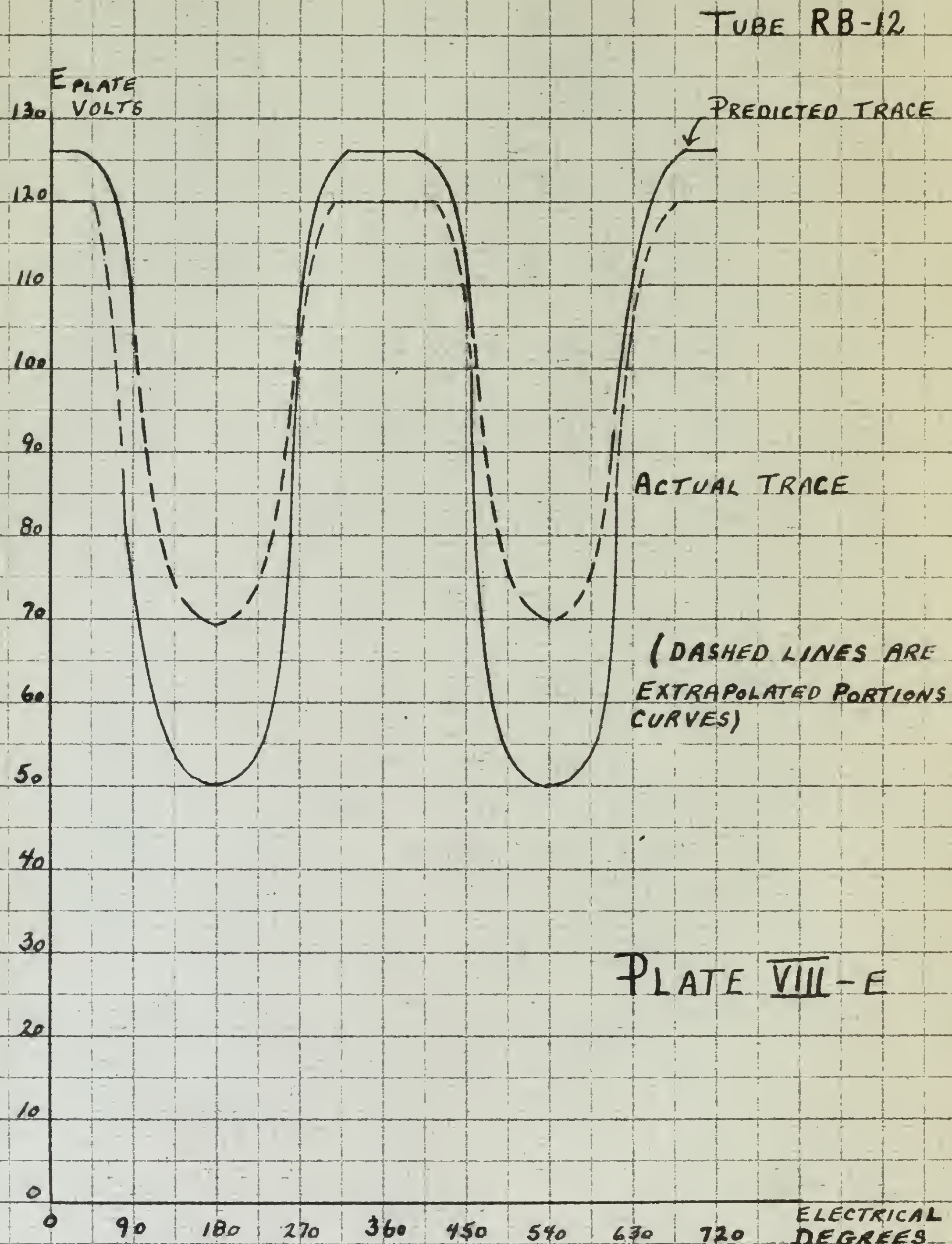

TUBE RB-12
E PLATE VOLTS
130
120
110
100
90
80
70
60
50
40
30
20
10
0
PREDICTED TRACE
ACTUAL TRACE
(DASHED LINES ARE EXTRAPOLATED PORTIONS OF CURVES)
0
90
180
270
360
450
540
630
720
ELECTRICAL DEGREES

PLATE VIII-E

was computed from direct observation of the output voltage wave shape on the oscilloscope, as previously mentioned. Since the wave shape was made up of plate and signal voltage components essentially, and since a grid current not in excess of 5 m.a. per tube was desired, it was not difficult to obtain a combination of signal and plate voltage which gave the desired power output. On the first test run with Manufacturer "S" Tubes the plate supply voltage was set at 130 V. because this was the value given for the transmitter amplifier tube. The signal voltage was then adjusted to give an output approximately equal to the average value obtained on tests of the transmitter. In subsequent tests the plate voltage and signal voltage were increased to obtain the increased power desired.

c) The signal voltage was set initially and after each shut down. The shut downs were at approximately 30 minute intervals throughout the 20 hour tests.

d) The total plate supply current was recorded before each shutdown with signal voltage on and after each shutdown before the signal voltage was turned on again.

e) The grid current was recorded and averaged approximately each hour during the 20 hour tests.

f) On the first few tests, before it was known how long the tubes would last, static tests were run after about 10 hours operation. This was discontinued when it was seen to be no longer necessary, and only one static test at the end of 20 hours of operation was made.

g) The shutdowns consisted of turning off all voltages on the tubes, allowing heater filaments to lose their visible glow and then again applying tube heater, plate, and signal voltages in that order.

h) Wave shape was observed several times during each test on two or three tubes for the first tests and later on all tubes.

d) The total plate supply current was recorded before each shutdown with signal voltage on and after each shutdown before the signal voltage was turned on again.

e) The grid current was recorded and averaged approximately each hour during the 80 hour tests.

f) On the first few tests, before it was known how long the tubes would last, static tests were run after about 10 hours operation. This was discontinued when it was seen to be no longer necessary, and only one static test at the end of 80 hours of operation was made.

g) The shutdowns consisted of turning off all voltages on the tubes, allowing heater filaments to lose their visible glow and then again applying tube heater, plate, and signal voltages in that order.

h) Wave shape was observed several times during each test on two or three tubes for the first tests and later on all tubes.

Description of Individual Tests

Test 1 - 20 hours. Average Power $\doteq$ 0.8 watt/tube. Tubes - SA1-SA10. (These tubes had been operated under varying conditions for several hours prior to test in setting up the test circuit).

Tube SA-10 failed after 30 minutes operation. The failure was noted by the sharp drop in plate supply voltage, and a sharp rise in total plate current. When this tube was placed in the tester, its heater circuit drew only about one third normal current, plate voltage would not build up, plate current rose quickly to many times its normal value as plate voltage was applied and its indicated transconductance was almost zero.

Summary of data taken in connection with test:

	Before Test	After Test	Change
Average Plate Current	10.3 m.a.	8.9 m.a.	-1.4 m.a.

Before Test	After Test	Change
Average Trans-conductance 3460 micromhos	3320 micromhos	-140
Maximum Change in Plate current due to test	-1.6 m.a.	
Maximum Change in Transconductance due to test	-280 micromhos	

Average grid current during test: 0.28 m.a.

Plate Supply Voltage 145 V. for 10 hours; 130 V. for 10 hours; Average Signal voltage 4.23 V. (r.m.s.).

Remarks: Failure of Tube SA-10 attributed to use prior to this test.

<u>Test 2</u> - 20 hours. Average Power ≑ 0.81 watt/tube. Tubes - SB1-SB10. No failures occurred during test.

<u>Summary of data taken in connection with test:</u>

	Before Test	After Test	Change
Average Plate Current	15.3 m.a.	12.0 m.a.	-3.3
Average Trans-conductance	4293 micromhos	3885 micromhos	-408

Maximum Change in transconductance due

to test -860

Average grid current during test 0.255 m.a.

Plate Supply Voltage 130 V. Average Signal

Voltage 4.27 V. (r.m.s.)

<u>Test 3</u> - 20 hours. Average Power $\doteq$ 1.12

watts/tube. Tubes SB11-SB18, SB20, SB21.

No failures occured during test.

<u>Summary of data taken in connection with test:</u>

	<u>Before Test</u>	<u>After Test</u>	<u>Change</u>
Average Plate Current	16.1 m.a.	10.4 m.a.	-5.7
Average Trans-conductance	4371 micromhos	3053 micromhos	-1318

Maximum Change in Plate Current due to test

-8.9 m.a.

Maximum Change in Transconductance due to

test -1800 micromhos

Average grid current during test 0.145 m.a.

Plate supply voltage 165,170,180 V. Average Signal voltage 6.04V (r.m.s.)

Test 4 - 20 hours. Average Power ≐ 1.6 watts/tube. Tubes SC-2-SC7, SC9, SC10, SC11, SC13. No failures occurred during test. Tube SC1 failed to operate when test was started. This tube tested perfectly on static test and had not been used between static and dynamic tests.

Summary of data taken in connection with test:

	Before Test	After Test	Change
Average Plate Current	11.7 m.a.	6.5 m.a.	-5.2
Average Transconductance	3899 micromhos	2447 micromhos	-1452

Maximum Change in Plate Current due to test -7.5 m.a.

Maximum Change in Transconductance due to test -1980 micromhos

Average grid current during test 0.189 m.a.

Plate supply voltage 200 V. Average Signal Voltage 6.24 V. (r.m.s.)

<u>Test 5</u> - 20 hours. Average Power ≐ 1.5 watts/tube. Tubes SA11-SA20. No failures occurred during test.

<u>Summary of data taken in connection with test:</u>

	Before Test	After Test	Change
Average Plate Current	10.9 m.a.	7.31 m.a.	-3.59
Average Transconductance	3572 micromhos	2624 micromhos	-948

Maximum Change in plate current due to test -6.2

Maximum Change in Transconductance due to test -1440 micromhos

Average grid current during test 0.258 m.a.

Plate Supply Voltage 200 V. Average Signal Voltage 6.02 V. (r.m.s.)

<u>Test 6</u> - 20 hours. Average Power ≐ 0.60 watt/tube. Tubes RA-1-RA6, RA8, RA-9, RA10. No failures occurred during test.

	Before Test	After Test	Change
Average Plate Current	11.7 m.a.	10.95 m.a.	-.75
Average Trans-conductance	4150 micromhos	3920 mi-cromhos	-230

Maximum Change in Plate Current Due to test

-2.2 m.a.

Maximum change in Transconductanse due to

test -530 micromhos

Average grid current during test 0.611 m.a.

Plate Supply Voltage 135V. Average Signal

Voltage 4.87 V. (r.m.s.)

Remarks: On some tubes the output wave showed distortion in addition to the usual flat portions. The tubes in which this distortion appeared however, were no different in static characteristics from the other tubes.

Test 7- 20 hours. Average Power ± 1.2 watts/tube. Tubes RE1-RE10. No failures occurred during test.

Summary of data taken in connection with test:

	Before Test	After Test	Change
Average Plate Current	10.66 m.a.	11.16 m.a.	+0.50
Average Trans-conductance	3982	3863	-119

Maximum Change in Plate Current due to test +2.7 m.a.

Maximum Change in Transconductance due to test -340 micromhos

Average grid current during test 0.288 m.a.

Plate Supply Voltage 200V. Average Signal Voltage 5.09 V. (r.m.s.)

Remarks: Output wave on some tubes showed considerable "jitter" in amplitude (see Photograph #3). The maximum amplitude of the wave was not clearly defined but covered three or four small divisions on the Cathode Ray Tube scale. The tubes in which this was observed showed no differences on static test from the other tubes.

Test 8 - 20 hours. Average Power ≐ 1.59 watts/tube. Tubes RC1-RC10. No failures occurred during test.

Summary of data taken in connection with test:

	Before Test	After Test	Change
Average Plate Current	8.88 m.a.	9.50 m.a.	+0.62
Average Trans-conductance	3626 micromhos	3531 micromhos	-95

Maximum Change in Plate current due to test +8.0 m.a.

Maximum Change in Transconductance due to test -800 micromhos

Average grid current during test 0.326 m.a.

Plate Supply Voltage 235 V. Average Signal Voltage 6.25 V. (r.m.s.)

Remarks: Same as for Test 7.

Test 9 - 20 hours. Average Power ≐ 1.49 watts/tube. Tubes RC11-RC20. No failures occurred during test.

Summary of data taken in connection with test:

	Before Test	After Test	Change
Average Plate Current	8.67 m.a.	8.35 m.a.	-0.32
Average Trans-conductance	3534 micromhos	3437 micromhos	-97

Maximum Change in Transconductance due to test -500 micromhos

Average grid current during test 0.336 m.a.

Plate Supply Voltage 235 V. Average Signal Voltage 6.26 V. (r.m.s.)

A comparison of the changes of tube parameters with use can be quickly obtained by reference to the table below. The first test made on Manufacturer "S" Tubes has been omitted because of the use of these tubes prior to testing.

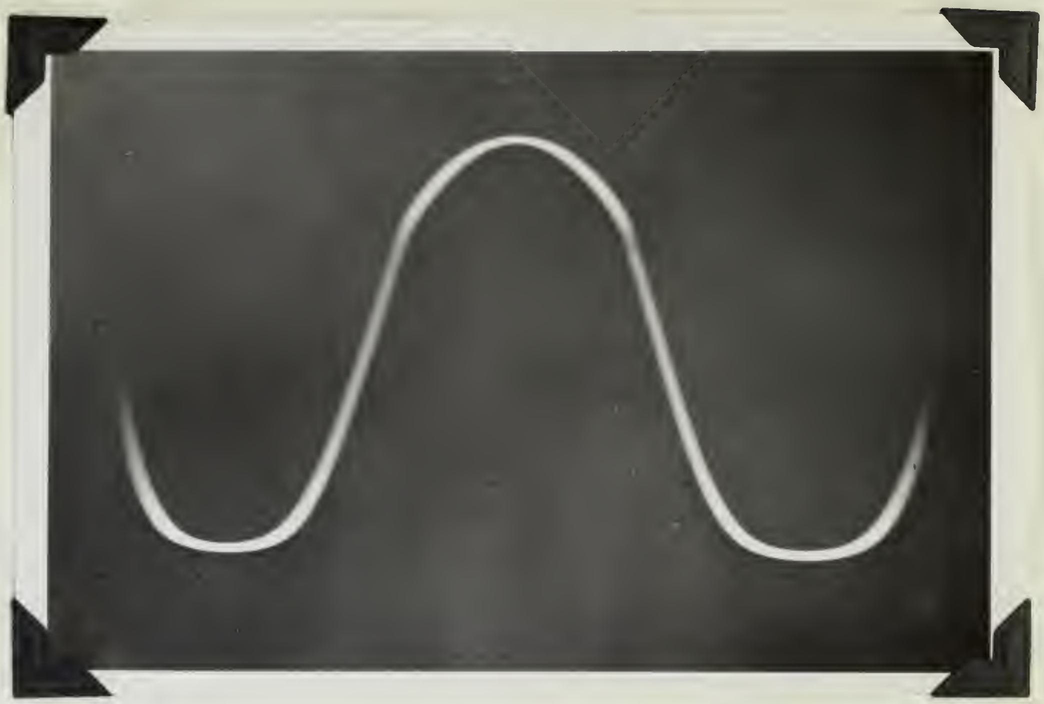
Manufacturer "S" Tubes

Test	$P_{average}$ tube(watts)	Milliamps Change in Av. I_{plate}	Micromhos Change in Av. g_m	% change in g_m
2	0.81	-3.30	- 406	9.52
3	1.12	-5.70	-1318	30.15
4	1.60	-6.20	-1452	37.35
5	1.50	-3.59	- 948	26.55
Aver.	1.26	-4.94	-1031	25.9

Manufacturer "R" Tubes

Test	$P_{average}$ tube(watts)	Milliamps Change in Av. I_{plate}	Micromhos Change in Av. g_m	% change in g_m
6	0.60	-0.75	-230	5.55
7	1.20	+0.50	-119	2.98
8	1.59	+0.62	- 95	2.62
9	1.49	-0.32	- 97	2.75
Aver.	1.22	+0.012	-135.2	3.48

Photographs which follow are typical output voltage wave forms on the oscilloscope for different tubes.



Manufacturer "S" Tube

Output Voltage Wave

Photograph 1

Manufacturer "R" Tube

Output Voltage Wave

Photograph 2

Manufacturer "R" Tube Output Voltage Wave, illustrating "noise" or "jitter" appearing on some Manufacturer "R" Tubes - Photograph 3.

Upon completion of the nine tests described above, it was decided that sufficient data had been obtained on the short time capabilities of the tubes. Supplementary tests were run to determine how long tubes would operate before failing completely; or if this was not possible, due to excessive time requirements, what comparative changes in tube characteristics and power output would occur due to operation. Tests Four and Nine were continued with the same tubes operating at the same plate and signal voltages until each set of tubes had operated for 60 hours. The tubes were operated continuously for periods of about eight hours with no shutdowns until the 60 hours operation was completed. The following results were obtained from these tests:

a) No failures occurred on either Manufacturer "S" or Manufacturer "R" Tubes.

b) The total changes in parameters for the

60 hour tests were as tabulated below:

	Average G_m after 60 hrs.	Average G_m before test	Average ΔG_m	Average ΔI_{plate}
Manufacturer "S" Tubes SC2-7,9,10,11,13	2667	3899	-1232	-5.05
Manufacturer "R" Tubes RC11 - 20	3528	3534	- 6	+0.40

G_m in micromhos

I_{plate} in milliamps

e) Tubes SC4 and RC13 respectively were the low tubes in power output during the twenty hour tests. During 52 hours operation Tube SC4 power output dropped 22%. During 55 hours operation Tube RC13 power output did not change.

Since there were no failures on either manufacturer's tubes due to the Dynamic Tests, it cannot definitely be stated that Manufacturer "R" Tubes will outlast Manufacturer "S"

Tubes. It seems definitely proven; however, that the characteristics of Manufacturer "P" Tubes change less with operation under normal and overload conditions than do the characteristics of Manufacturer "S" Tubes. This change in characteristics results in the loss of power output observed in Manufacturer "S" Tubes.

CHAPTER IV

ATTEMPTED CORRELATION BETWEEN STATIC TESTS AND TUBE CHARACTERISTICS DURING LIFE

As was stated in the introduction, one of the purposes of the tests was to predict tube life under dynamic conditions from measurements made in a static tester. The following attempts at correlation were made. It is important to note that on the twenty hour tests of fifty Manufacturer "S" and forty Manufacturer "R" Tubes, there was but one failure. This failure occurred after 1/2 hour on a tube which prior to the actual test had been operated several hours at many different voltages in the simulator while the simulator was being set up. Because there was only one failure and this was on a tube whose g_m was only 1700 micromhos at the beginning of the test, as compared to 3700 micromhos average for the lot from which it was taken, the failure cannot be attributed

to the operation during the test period.

Since there were no failures of normal tubes, the best method of measuring useful life left in the tubes after test is to measure their transconductance. In the following attempts at correlation, this criterion was used.

The change in transconductance between normal plate voltage and normal plate voltage less 20 volts was computed from static tests. This change was compared with the final value of transconductance. The results showed no apparent correlation between change in g_m and final value of g_m as will be seen by referring to the tables below which are for tubes used in two separate tests.

Tube	Original g_m micromho	Final g_m Micromho	Δg_m for E_{plate} lowered 20 volts
SA-1	3600	3100	-725
2	3500	3000	-700
3	3920	3680	-1020
4	4320	3200	-825

Tube	Original g_m micromho	Final g_m Micromho	Δg_m for E_{plate} lowered 20 volts
SA-5	4200	3800	-870
6	3450	3300	-800
7	3500	3000	-800
RB-1	3630	3600	-630
2	4300	4270	-670
3	4000	3700	-530
4	3800	3730	-650
5	4550	4600	-650
6	3620	3300	-450
7	4150	3950	-550
8	3670	3520	-445
9	3900	3560	-520
10	4200	4400	-680

Similar comparisons made with ten other tubes of each type also failed to show any correlation between change in g_m and final value of g_m.

The next change investigated for possible relation to the final value of g_m

was the change in transconductance for a reduction in heater voltage from 6.3 to 4.0 volts. The percentage change in g_m at 4.0 volts was computed, and this was plotted against original g_m for several of the tubes of both manufacture that had been tested dynamically. It was thought possible that with such a plot one would be able to select quickly desirable tubes which had high g_m and small change in g_m for change in heater voltage. The data from which two such plots were made appears in Table I of Appendix II together with the predictions on the relative values of transconductance at the end of twenty hours operation. The tube which it was predicted would have highest value of g_m at the end of twenty hours operation was called 1st, the tube predicted to have next highest value 2nd and so forth. These predictions were made by using the plots of Plates IX and X. At the same time predictions were made on the

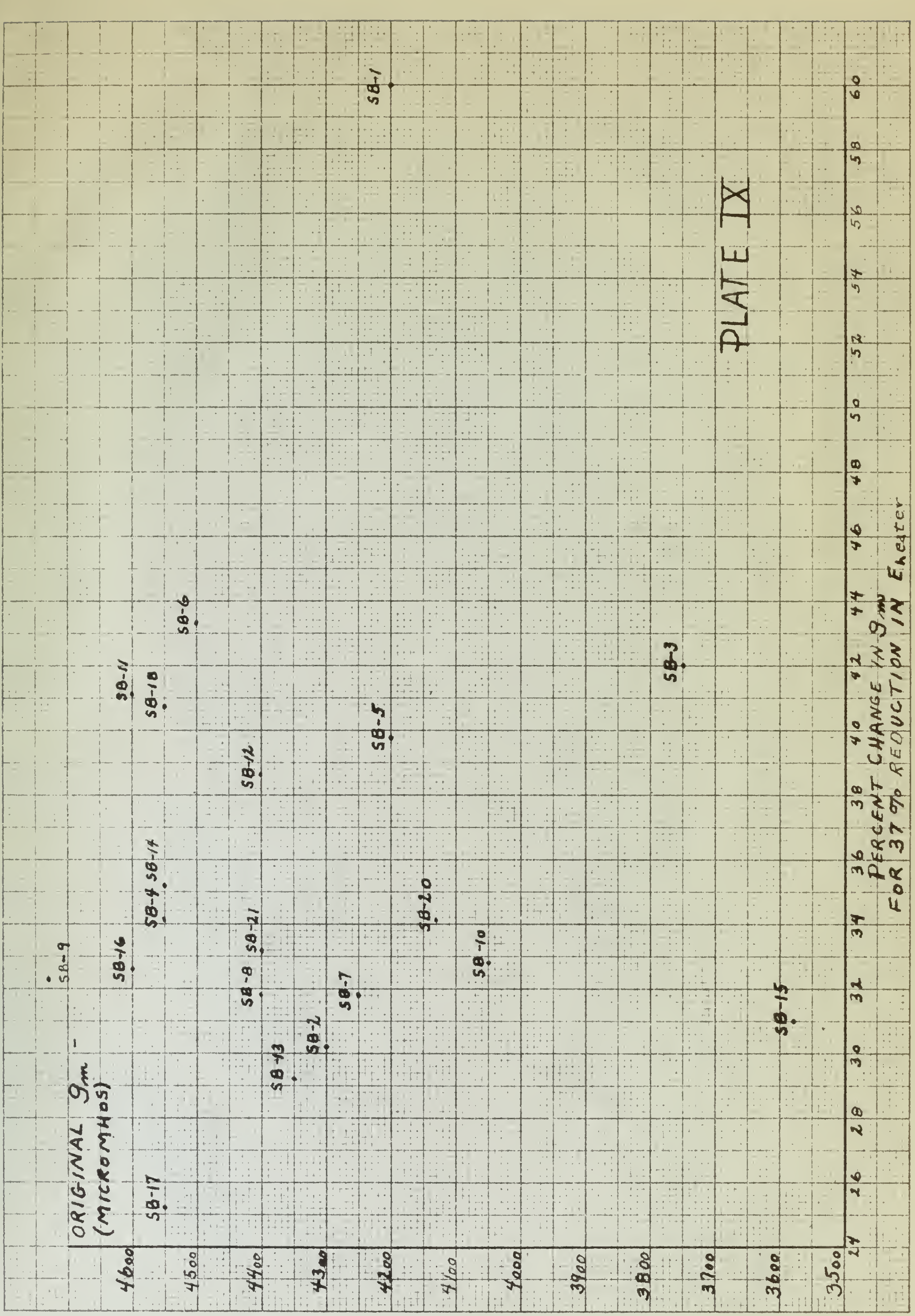


PLATE IX
ORIGINAL g_m
(MICROMHOS)
PERCENT CHANGE IN g_m
FOR 37% REDUCTION IN E_{heater}
4600
4500
4400
4300
4200
4100
4000
3900
3800
3700
3600
3500
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
SB-1
SB-2
SB-3
SB-4
SB-5
SB-6
SB-7
SB-8
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SB-15
SB-16
SB-17
SB-18
SB-20
SB-21

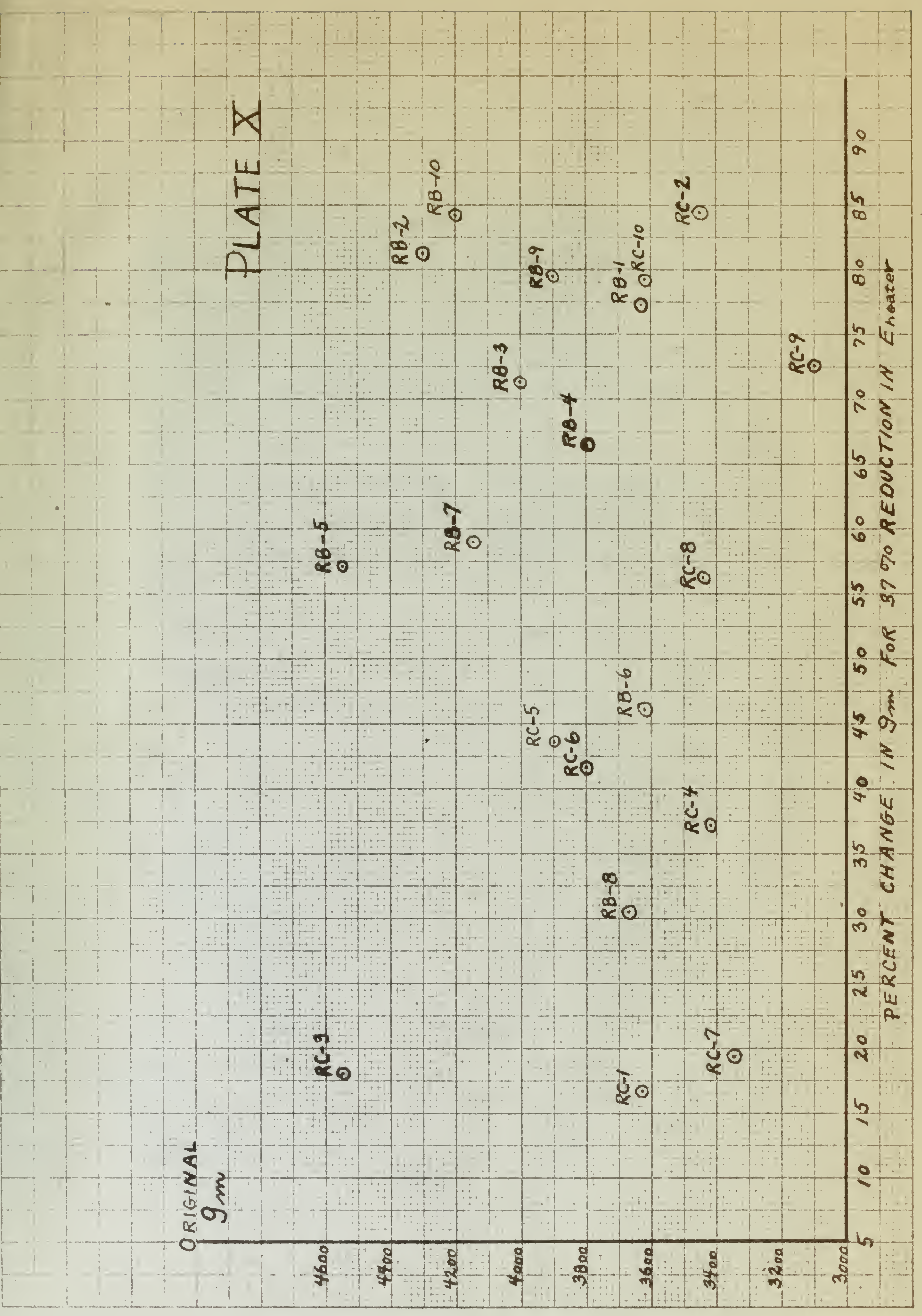
PLATE X
ORIGINAL g_m
4600
4400
4200
4000
3800
3600
3400
3200
3000
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90
PERCENT CHANGE IN g_m FOR 37% REDUCTION IN E_{heater}
RB-10
RB-2
RC-2
RB-9
RB-1
RC-10
RC-9
RB-3
RB-4
RB-7
RB-5
RC-8
RB-6
RC-5
RC-6
RC-4
RB-8
RC-3
RC-7
RC-1

basis of original value of g_m alone. The errors in predicting the relative values of g_m after twenty hours operation by use of the plot and by use of the original value of g_m are given below for two groups of ten tubes each.

Tube	Error in relative g_m after operation using original g_m to predict	Error in relative g_m after operation using plot to predict
SR-11	4	1
12	6	1
13	0	1
14	2	0
15	1	3
16	6	1
17	0	1
18	1	4
20	3	1
21	3	1
Average	2.0	Average 1.4
SB-1	2	1
2	1	2

Tube	Error in relative g_m after operation using original g_m to predict	Error in relative g_m after operation using plot to predict
SB-3	1	1
4	2	2
5	1	1
6	2	7
7	1	2
8	2	1
9	2	2
10	2	1
Average	1.7 Average	2.0

The results of four more tests of twenty hours each were used to make identical calculations. The computations will not be shown here but the results were:

Tube	Average error in relative g_m after operation using original g_m to predict	Average error in relative g_m after operation using plot to predict
S[illegible] 2-13	2.60	3.40
SA 11-20	1.33	1.22
RB 1-10	1.00	2.80
RC 1-10	2.40	3.40

The results of the six tests show that the average error in relative g_m after test is usually less by using the original value of g_m to predict value after test. These results preclude the use of the plot as tubes that start life with high g_m usually continue to have high g_m relative to tubes starting life with low g_m.

The next quantity investigated for its effect on tube life was plate resistance. Values of r_p were computed at rated heater voltage and at 4.0 volts heater voltage. The change in plate voltage in each case was 20 volts.

Results of these computations are given in Table II of Appendix II for ten Manufacturer "S" and nine Manufacturer "R" Tubes. The Δr_p is simply change in r_p for a change of -2.3 volts heater voltage.

There appears to be no correlation between Δr_p and final value of g_m nor between Δr_p and Δg_m.

No further attempts were made to correlate the results of Static Tests with tube characteristics during life. A search of available literature failed to disclose any information as to what attempts had been made by others to perform such a correlation aside from making the usual measurements in a tester of Plate Current, Plate Resistance, and Transconductance at rated values of Plate and Heater Voltage.

Chapter V

Conclusions

On the basis of static tests, Manufacturer "R" Tubes are more uniform in characteristics than Manufacturer "S" Tubes. "R" Tubes show fewer percentages of bad tubes from a random selection. Their parameters are more nearly what their manufacturers give as typical parameters.

The average value of transconductance, which is usually considered the best criterion of design proficiency of a tube, was greater for 98 Manufacturer "R" Tubes than for an equal number of Manufacturer "S" Tubes.

On the basis of dynamic tests simulating performance in one particular application, Manufacturer "R" Tubes show much smaller percentage change in both static characteristics and power output than Manufacturer "S" Tubes. While no definite value of tube life was obtained for either manufacturer's tubes, it

is highly probable that Manufacturer "P" Tubes will outlive Manufacturer "S" Tubes.

No simple method is apparent from the results of these experiments by which the parameters measured on static tests can be used to predict changes in characteristics which may result from tube operation.

is highly probable that manufacturer "B" Tubes will outlive manufacturer "D" Tubes.

No simple method is apparent from the results of these experiments by which the parameters measured on static tests can be used to predict changes in characteristics which may result from tube operation.

APPENDIX I

TABLE I

Manufacturer	Manufacturer's Lot No.	Symbol	Number of Tubes	Tube Designations
"S"	R25589D	SA	35	SA1, SA2,...SA35
"S"	R25589C	SB	35	SB1, SB2,...SB35
"S"	R26255	SC	35	SC1, SC2,...SC35
		Total	105	
"R"	148	RA	10	RA1, RA2,...RA10
"R"	298	RB	26	RB1, RB2,... RA26
"R"	438	RC	24	RC1, RC2,...RC24
"R"	488	RD	40	RD1, RD2,...RD40
		Total	100	

TABLE II

Manufacturer "S" - 6K4A Tubes

Tube	Milliamp Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
SA 1	10.0	3600	4760	1.2	360	95
" 2	10.3	3500	4760	.9	360	195
" 3	11.7	3920	4760	.5	360	225
" 4	12.8	4320	4445	1.6	45	625
" 5	13.5	4200	3840	2.3	560	505
" 6	9.5	3450	4650	1.7	250	245
" 7	11.3	3500	3840	.1	560	195
" 8	16.0	4400	3510	4.8	890	705
" 9	10.0	3350	4650	1.2	250	345
" 10	9.0	3120	4760	2.2	360	575
" 11	14.0	4170	3510	2.8	890	475
" 12	14.1	3900	3640	2.9	760	205
" 13	8.8	3270	5125	2.4	725	425
" 14	11.5	3650	4080	.3	320	45
" 15	9.1	3370	5125	2.1	725	325
" 16	9.0	3300	48.75	2.2	475	395
" 17	11.6	3700	4000	.4	400	5
" 18	10.3	3480	4545	.9	145	215

Tube	Milliamp Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
SA19	8.7	3350	5125	2.5	725	345
" 20	11.9	3600	4000	.7	400	95
" 21	12.5	3820	3840	1.3	560	125
" 22	15.2	4400	3390	4.3	1010	705
" 23	15.8	4620	3570	4.6	830	925
" 24	9.0	3320	5000	2.2	600	375
" 25	10.4	3600	4445	.8	45	95
" 26	9.1	3300	5260	2.1	860	395
" 27	12.3	3870	3920	1.1	480	175
" 28	Bad Tube					
" 29	8.5	3400	5550	2.7	1150	295
" 30	11.7	3920	4445	.5	45	225
" 31	11.7	3950	4080	.5	320	255
" 32	10.5	3700	4445	.7	45	5
" 33	13.0	3720	3840	1.8	560	25
" 34	8.7	3240	5125	2.5	725	455
" 35	9.8	3500	4650	1.4	250	195
Totals	381.3	125510	149610	60.2	16000	10610
Average = 1/34 x Totals	11.20	3695	4400	1.77	470	312

TABLE III

Manufacturer "S" - 6K4A Tubes

Tube	Milliamp Iplate	Micromho gm	Ohms rp	Vari- ation from mean Ip	Vari- ation from mean rp	Vari- ation from mean gm
SD 1	14.4	4200	4000	1.2	530	120
" 2	14.4	4300	3700	1.2	230	20
" 3	12.1	3750	4080	3.5	610	570
" 4	16.9	4550	3330	1.3	140	230
" 5	15.5	4200	3640	0.1	170	120
" 6	17.1	4500	3080	1.5	390	180
" 7	15.8	4250	3180	.2	290	70
" 8	15.0	4400	3445	.6	25	80
" 9	17.3	4730	3180	1.7	390	410
" 10	14.0	4050	3450	1.6	20	270
" 11	19.0	4600	2990	3.4	480	280
" 12	17.3	4400	3445	1.7	25	80
" 13	14.4	4350	3510	1.2	40	30
" 14	16.8	4550	3330	1.2	140	230
" 15	11.9	3580	3920	3.7	450	740
" 16	15.8	4600	3510	.2	40	280
" 17	15.6	4550	3700	.0	230	230
" 18	18.4	4550	2940	3.2	530	230

Tube	Milliamp Iplate	Micromho gm	Ohms rp	Variation from mean I_p	Variation from mean rp	Variation from mean gm
SB 19	Bad Tube					
" 20	16.5	4130	3510	.9	40	190
" 21	15.5	4400	3700	.1	230	80
" 22	19.0	4580	3175	3.4	295	260
" 23	12.3	3900	3775	3.3	305	420
" 24	13.1	4200	3575	2.5	105	120
" 25	18.2	4400	3125	2.6	345	80
" 26	17.3	4600	3175	1.7	295	280
" 27	16.0	4420	3640	.4	170	100
" 28	15.3	4070	3390	.3	80	250
" 29	15.3	4320	3570	.3	100	0
" 30	15.3	4200	3390	.3	80	120
" 31	15.6	4400	3700	.0	230	80
" 32	16.3	4600	3450	.7	20	280
" 33	Bad Tube					
" 34	13.1	3820	3510	2.5	40	500
" 35	14.5	4480	3390	1.1	80	160
Totals	5140	142630	114505	47.6	7145	7090

Average = 1/33 x Total

	15.6	4320	3470	1.44	216.2	214.7

TABLE IV

Manufacturer "S" - 6K4A Tubes

Tube	Milliamp Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
SC 1	11.3	3400	3920	0	130	275
" 2	12.0	3920	3920	.7	130	245
" 3	10.3	3520	4445	1.0	295	155
" 4	13.8	4160	3570	2.5	580	485
" 5	8.2	3300	5550	3.1	1400	375
" 6	14.0	4350	3510	2.7	640	675
" 7	10.6	3820	4445	.7	295	145
" 8	Bad Tube					
" 9	10.6	3600	4350	.7	200	75
" 10	11.3	3750	4170	.0	80	75
" 11	13.4	4120	3920	2.1	230	445
" 12	Bad Tube					
" 13	12.8	4450	3775	1.5	375	775
" 14	14.3	4250	3125	3.0	1025	575
" 15	Bad Tube					
" 16	10.0	3660	4250	1.3	100	15
" 17	13.4	4470	3635	2.1	515	795
" 18	10.3	3350	4170	1.0	20	325

Tube	Milliamp Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
3C19	14.5	3900	3570	3.2	580	225
" 20	10.6	3500	4000	.7	150	175
" 21	13.5	4190	3775	2.2	375	515
" 22	8.9	3330	5260	2.4	1110	345
" 23	10.6	3620	4080	.7	70	55
" 24	9.1	3300	4760	2.2	610	375
" 25	10.3	3500	4350	1.0	200	175
" 26	12.0	3800	3845	.7	305	125
" 27	10.1	3680	4255	1.2	105	5
" 28	11.3	3680	4170	0	20	5
" 29	Bad Tube					
" 30	9.5	3400	4760	1.8	610	275
" 31	13.5	3910	3700	2.2	450	235
" 32	8.8	3400	4080	2.5	70	275
" 33	12.3	3800	3700	1.0	450	125
" 34	12.0	3920	4250	.7	150	245
" 35	7.9	3200	5550	3.4	1400	475
Totals	351.2	116250	128860	48.3	12670	9065
Average = 1/31 x Totals						
	11.3	3675	4150	1.56	408	292

TABLE V

Manufacturer "R" - CK6008CX Tubes

Lot 148 Tube	Milliamps Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
RA 1	10.3	4150	5260	1.4	940	0
" 2	11.0	3840	4650	.7	330	310
" 3	13.0	4220	3775	1.3	545	70
" 4	11.5	4400	4080	.2	240	250
" 5	13.4	4650	3920	1.7	400	500
" 6	10.3	3630	4160	1.4	160	520
" 7	Bad Tube					
" 8	12.2	4080	4250	.5	70	70
" 9	12.6	4320	4350	.9	30	170
" 10	11.0	4000	4445	.7	125	150
Totals	105.3	37290	38900	8.8	2840	2040
Average = 1/9 x Totals						
	11.7	4150	4320	.98	316	226.5

TABLE VI

Manufacturer "B" - [illegible] Tubes

Lot 298

Tube	Milliamps Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
RB 1	7.7	3630	6250	3.3	1370	350
" 2	12.4	4300	4075	1.1	805	320
" 3	11.5	4000	4760	.5	120	20
" 4	10.4	3800	5000	.6	120	180
" 5	13.3	4550	4080	2.3	800	570
" 6	10.2	3620	5000	.8	120	360
" 7	10.7	4150	4675	.3	5	170
" 8	9.1	3670	6450	1.9	1570	310
" 9	10.2	3900	4875	.8	5	80
" 10	11.1	4200	4250	.1	630	220
" 11	10.4	4000	5400	.6	520	20
" 12	13.2	4450	4000	2.2	880	470
" 13	10.7	3900	4650	.3	230	80
" 14	11.0	3840	4875	.0	5	140

Tube	Milliamps Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
RB15	12.3	4220	4445	1.3	435	240
" 16	13.1	4380	4550	2.1	330	400
" 17	10.8	3780	4760	.2	120	200
" 18	13.2	4200	4080	2.2	800	220
" 19	12.2	4020	4550	1.2	330	40
" 20	11.2	3820	4875	.2	5	160
" 21	10.2	3800	5260	.8	380	180
" 22	11.4	3800	4875	.4	5	180
" 23	9.2	3900	5700	1.8	820	80
" 24	9.8	3770	5125	1.2	245	210
" 25	10.7	4100	4650	.3	230	120
" 26	9.4	3700	5550	1.6	670	280
Totals	285.4	103500	126900	28.5	11550	5600

Average = 1/26 x Totals

11.0	3980	4880	1.095	444	215

TABLE VII

Manufacturer "R" - 6AC5GT Tubes

Lot 438

Tube	Milliamps Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
RG 1	10.3	3630	5260	1.3	670	30
" 2	8.9	3450	5715	.1	215	210
" 3	5.5	4550	7400	3.5	1470	890
" 4	8.4	3420	6900	.6	970	240
" 5	8.4	3900	5880	.6	50	240
" 6	11.5	3800	5000	2.5	930	140
" 7	10.4	3350	5400	1.4	530	310
" 8	10.2	3440	5125	1.2	805	[illegible]
" 9	7.0	3100	6450	2.0	520	500
" 10	8.2	3620	8340	.8	2410	40
" 11	7.6	3600	6000	1.4	130	60
" 12	8.7	3550	5720	.3	210	110

Tube	Milliamps Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
RG13	8.6	3700	6450	.4	520	40
" 14	5.8	3080	8340	3.2	2410	580
" 15	10.2	3500	5400	1.2	530	160
" 16	10.2	3500	5400	1.2	530	160
" 17	7.6	3330	7150	1.4	1220	330
" 18	8.9	3480	5550	.1	380	180
" 19	10.9	4000	4700	1.9	1170	340
" 20	8.2	3600	6450	.8	520	60
" 21	Bad Tube					
" 22	10.4	4200	5130	1.4	800	540
" 23	10.2	4100	4760	1.2	1170	440
" 24	11.0	4260	3570	2.0	2360	600
Totals	207.3	84160	136210	30.5	20520	6460
Average = 1/23 x Totals						
	9.0	3660	5930	1.325	892	281

TABLE VIII

Manufacturer "R" - CK608CX Tubes

Lot 488 Tube	Milliamps Iplate	Micromho	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
RD 1	9.1	3800	5400	.7	220	245
" 2	7.8	3640	6050	2.0	870	405
" 3	8.8	3800	5710	1.0	530	245
" 4	10.1	3900	4540	.3	640	145
" 5	9.8	3940	4880	0	300	105
" 6	9.0	3700	5710	.8	530	345
" 7	11.7	4420	4440	1.9	740	375
" 8	10.6	4180	4700	.8	420	135
" 9	10.4	4300	4650	.6	530	255
" 10	10.5	4120	4760	.7	420	75
" 11	10,4	4100	4880	.6	300	55
" 12	9.2	4000	5400	.4	220	45
" 13	8.6	4000	5880	1.2	700	45

Tube	Milliamps Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
RD 14	8.8	3870	5550	1.0	370	175
" 15	11.2	4000	4880	1.4	300	45
" 16	10.7	4500	4760	.9	420	455
" 17	13.4	4400	4080	3.6	1100	355
" 18	10.4	4000	5330	.6	150	45
" 19	10.0	4080	4550	.2	630	35
" 20	8.4	3700	6055	1.4	875	345
" 21	10.4	4180	4760	.6	420	135
" 22	11.4	4670	4265	1.6	1015	625
" 23	8.8	3720	5880	1.0	700	325
" 24	7.8	3800	6250	2.0	1070	245
" 25	10.2	4100	4880	.4	300	55
" 26	8.2	3850	5550	1.6	370	195

Tube	Milliamps Iplate	Micromho gm	Ohms rp	Variation from mean Ip	Variation from mean rp	Variation from mean gm
R027	11.4	4470	4760	1.6	420	425
" 28	8.5	4050	6050	1.3	870	5
" 29	10.5	4380	4250	.7	930	335
" 30	10.2	4050	5130	.4	50	5
" 31	10.2	4100	5000	.4	180	55
" 32	9.2	4220	4880	.6	300	175
" 33	9.9	4100	4760	.1	420	55
" 34	8.2	3650	6040	1.6	860	395
" 35	10.2	4230	4880	.4	300	185
" 36	11.0	4150	4445	1.2	735	105
" 37	8.8	3700	5710	1.0	530	345
" 38	10.2	4040	4880	.4	300	5
" 39	9.5	4100	5260	.3	80	55
" 40	8.4	3800	5630	1.4	450	245
Totals	391.9	161810	205405	28.7	1002.5	7800
Average = 1/40 x Totals						
	9.8	4045	5180	.717	266	195

TABLE IX

Average Variation from Mean Value

Tube Group	I_{plate}	Weighting Factor	Weighted Mean I_p
Manufacturer "S"			
SA	1.77	34/98	1.77 x 34 = 60.20
SB	1.44	33/98	1.44 x 33 = 47.50
SC	1.56	31/98	1.56 x 31 = 48.30
			sum 156.00
			156.0 ÷ 98 = 1.591
Manufacturer "R"			
RA	.98	9/98	.98 x 9 = 8.82
RB	1.01	26/98	1.01 x 26 = 26.25
RC	1.33	23/98	1.33 x 23 = 30.60
RD	.72	40/98	.72 x 40 = 28.80
			sum 94.47
			94.47 ÷ 98 = .963

TABLE X

Tube Lot	Tube	I_p at E_p of 100 V.	I_p at E_p of 80 V.	I_p at E_p of 60 V.	I_p at E_p of 50 V.	I_p at E_p of 33 V.
	Manufacturers	12.2	7.6	4.0	2.7	.9
5A	High Tube	16.0	10.3	5.2	3.3	1.0
	Low Tube	8.5	4.8	1.95	.95	.15
	Average	11.2	6.55	3.05	1.8	.44
	Manufacturers	12.2	7.6	4.0	2.7	.9
5B	High Tube	19.0	12.7	6.7	4.4	1.4
	Low Tube	11.9	6.8	3.2	1.9	.4
	Average	15.6	9.78	4.96	3.16	.94
	Manufacturers	12.2	7.6	4.0	2.7	.9
C	High Tube	14.5	8.9	4.5	2.8	.7
	Low Tube	8.8	3.9	1.9	1.0	.15
	Average	11.3	6.44	2.96	1.72	.37

All Values of I_p are Milliamps

Tube Lot	Tube	I_p at E_p of 120 V.	I_p at E_p of 100 V.	I_p at E_p of 80 V.	I_p at E_p of 60 V.	I_p at E_p of 48 V.
	Manufacturers	8.3	5.0	2.2	.75	0
RA	High Tube	13.4	8.3	4.8	1.7	.35
	Low Tube	10.3	6.5	3.4	1.3	.25
	Average	11.7	7.13	4.03	1.57	.283
	Manufacturers	8.3	5.0	2.2	.75	0
RB	High Tube	13.1	8.7	5.1	2.4	.5
	Low Tube	7.7	4.5	2.1	.55	.10
	Average	11.0	6.83	3.64	1.33	.23
	Manufacturers	8.3	5.0	2.2	.75	0
RC	High Tube	11.5	7.5	4.3	1.6	.3
	Low Tube	5.5	2.8	1.3	.4	.1
	Average	9.0	5.28	2.7	.88	.16
	Manufacturers	8.3	5.0	2.2	.75	0
RD	High Tube	13.4	8.5	4.7	1.9	.4
	Low Tube	7.8	4.5	2.0	.5	.05
	Average	9.8	5.86	2.87	.90	.142

All Values of I_p are Milliamps

TABLE XI

Sample Calculation of Power Output

Ordinate	Voltage = ord. x 4.9v.	e^2
0	0.0	0.0
.3	1.5	2.2
.6	2.9	8.6
.8	3.9	15.4
1.0	4.9	24.0
2.7	13.2	165.0
5.0	24.5	600.0
7.0	34.3	1175.0
10.0	49.0	2400.0
13.0	63.6	4030.0
15.0	73.5	5390.0
18.0	88.3	7700.0
20.0	98.0	9600.00
20.5	100.5	10050.0
21.0	103.0	10600.0
21.5	105.3	11080.0
22.0	107.8	11600.0
22.0	107.8	11600.0
21.7	106.2	11270.0
21.5	105.3	11080.0
22.0	107.8	11600.0

Ordinate	Voltage = ord. x 4.9v.	E^2
21.0	103.0	10600.0
21.0	103.0	10600.0
20.7	101.5	10270.0
20.3	99.5	9880.0
20.0	98.0	9600.0
19.0	93.1	8700.0
18.0	88.3	7760.0
17.0	83.4	6920.0
13.0	63.7	4050.0
10.0	49.0	2400.0
5.0	24.5	600.0
3.0	14.7	2214.0
1.0	4.9	24.0
.2	.98	.96
0	0.0	0.0
0	0.0	0.0
0	0.0	0.0
0	0.0	0.0
	Total	201469.2

Total E^2 = 201469.2 Average $E^2 = \frac{201469.2}{39}$ = 5030 volts ^{2}

Number of ordinates = 39 $P_{average} = \frac{E_{av}^2}{R} = \frac{5030}{3000} =$ 1.675 Watt

APPENDIX II

TABLE I

Tube	gm before test	Δ gm for 37% Lower Eheater	% change in gm
SB 1	4200	-2525	60.0
2	4300	-1300	30.2
3	3750	-1575	42.0
4	4550	-1550	34.1
5	4200	-1675	39.6
6	4500	-1950	43.3
7	4250	-1350	31.8
8	4400	-1400	31.8
9	4730	-1530	32.3
10	4050	-1330	32.8
11	4600	-1890	41.1
12	4400	-1700	38.6
13	4350	-1270	29.2
14	4550	-1600	35.2
15	3580	-1110	31.0
16	4600	-1500	32.6
17	4550	-1150	25.2
18	4550	-1850	40.7
20	4130	-1410	34.1
21	4400	-1460	33.2

Tube	gm after test	final relative position of gm (actual)	final relative position of gm (predicted)
TB 1	3340	9th	10th
2	3870	6th	4th
3	3200	10th	9th
4	3960	4th	2nd
5	3820	8th	7th
6	4420	1st	8th
7	3860	7th	5th
8	4300	2nd	3rd
9	4200	3rd	1st
10	3880	5th	6th
11	2930	5th	6th
12	2600	9th	8th
13	3100	4th	3rd
14	3100	4th	4th
15	2850	7th	10th
16	3700	1st	2nd
17	3500	2nd	1st
18	3150	3rd	7th
20	2700	8th	9th
21	2900	6th	5th

Tube	Relative position original gm
1	7th
2	5th
3	9th
4	2nd
5	7th
6	3rd
7	6th
8	4th
9	1st
10	8th
11	1st
12	3rd
13	4th
14	2nd
15	6th
16	1st
17	2nd
18	2nd
20	5th
21	3rd

TABLE I (continued)

Tube	gm before test	gm for 37% Lower Eheater	% change in gm	gm after test
RB 1	3630	825	77.3	3600
2	4300	800	81.3	4270
3	4000	1150	71.3	3700
4	3800	1275	46.2	3730
5	4550	1950	57.1	4600
6	3620	1950	46.2	3300
7	4150	1700	59.0	3950
8	3670	2550	30.5	3520
9	3900	800	79.5	3560
10	4200	660	84.2	4400

	Actual relative gm after test	Predicted relative gm after test	Original relative position of gm
1	7th	10th	9th
2	3rd	5th	2nd
3	6th	6th	5th
4	5th	7th	7th
5	1st	1st	1st
6	10th	4th	10th
7	4th	3rd	4th
8	9th	2nd	8th
9	8th	9th	6th
10	2nd	8th	3rd

Tube	gm before test	gm for 37% lower Eheater	% change in gm	gm after test
RC 1	3630	605	16.7	3300
2	3450	2900	84.5	3420
3	4550	820	18.0	3750
4	3420	1270	37.2	3600
5	3900	1700	43.6	3850
6	3800	1580	41.6	3320
7	3350	650	19.4	3280
8	3440	1940	56.4	3430
9	3100	2250	72.6	3400
10	3620	2870	79.3	3700

Tube	Actual relative gm after test	Predicted relative gm after test	Original relative position of gm
R6 1	8th	2nd	4th
2	6th	9th	6th
3	2nd	1st	1st
4	4th	6th	8th
5	1st	3rd	2nd
6	9th	4th	3rd
7	10th	5th	9th
8	5th	8th	7th
9	7th	10th	10th
10	3rd	7th	5th

TABLE II

Tube	r_p at 6.3V	r_p at 4.0V	Δr_p
5A 11	3510	6450	2940
12	3640	9100	5460
13	5125	11100	5975
14	4080	5880	1800
15	5125	8710	3585
16	4875	15400	10525
17	4000	10350	6530
18	4545	21050	16505
19	5125	9540	4415
20	4000	8350	4350
RA 1	5260	9520	3260
2	4650	11750	7100
3	3775	14300	10525
4	4080	13330	9250
5	3920	25000	21080
6	4160	9100	4840
8	4250	28600	24350
9	4350	13340	8990
10	4445	18200	13755

Tube	gm after test	gm before test	Δ gm due 20 hour test
SA11	2730	4170	-1440
12	2900	3900	-1000
13	2630	3270	-640
14	2590	3650	-1060
15	2560	3370	-810
16	2150	3300	-1150
17	2700	3700	-1000
18	2450	3480	-1250
19	2700	3350	-650
20	2830	3600	-770
RA1	3940	4150	-80
2	3700	3840	-170
3	3930	4220	-330
4	4280	4400	-300
5	4730	4050	-120
6	3320	3630	-460
8	3550	4080	-530
9	3950	4320	-370
10	3820	4000	-180

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VITA

The author was born in Norfolk, Virginia in October 1919.

He attended The Episcopal High School, Alexandria, Virginia for two years, and Culver Military Academy, Culver, Indiana for three years. He graduated from Culver in June 1937, and returned the following year for Junior College.

In July 1938 he entered the U.S. Naval Academy and was graduated with Bachelor of Science Degree in December 1941. Since graduation he has served as a Naval Officer.

He entered the U.S. Naval Postgraduate School, Annapolis, Maryland in July 1946 and in September 1947 entered The Johns Hopkins Engineering School as a graduate student in Electrical Engineering under the sponsorship of the Bureau of Ordnance, U.S. Navy.

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